STATE OF CALIFORNIA
The Resources Agency

# Department of Water Resources



## BULLETIN No. 104-6

# MEETING WATER DEMANDS IN THE RAYMOND BASIN AREA



JUNE 1971

NORMAN B. LIVERMORE, JR.
*Secretary for Resources*
*The Resources Agency*

RONALD REAGAN
*Governor*
*State of California*

WILLIAM R. GIANELLI
*Director*
*Department of Water Resources*

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Pasadena City Hall

# FOREWORD

At present, about half the water supply in California's South Coastal Area comes from its ground water basins. In general, the extractions from these basins exceed the replenishment, with the result that the elevations of the ground water levels are declining.

In several basins, water users have appealed to the courts to help determine the allocation of this scarce commodity. The first to come under court decree was the Raymond Basin of Los Angeles County in 1943.

Since then, technological developments have made possible more precise evaluation of ground water potentialities. These have been employed by the Department of Water Resources in a series of cooperative investigations of possible management plans for use by local agencies in a number of Southern California basins.

With this thought in mind, local water agencies, through the Raymond Basin Advisory Board, in 1966 requested the Department to work with them in such a study in their area. Their purpose was to be able to consider various ways for improvement of the management of the basin--both its ground water resources and its surface and imported water supplies.

The Board recognized in its request that the court-decreed safe yield should not be a limiting factor in the study; should it prove necessary, the Board could petition the court for a new evaluation.

Accordingly, a cooperative agreement was drawn up between the local agencies and the Department. Statutory authority for the Department to conduct investigations of surface and subsurface water is contained in Section 226 of the California Water Code. Authority for the investigation of subsurface water conditions is also conferred by the Porter-Dolwig Ground Water Protection Law, Water Code Section 12920 and those that follow, and Section 231.

In this investigation, comprehensive studies were made of the geology, hydrology, and operation-economics of the Raymond Basin. This bulletin summarizes the physical and economic information developed for four representative methods of ground water basin management from which the local agencies can plan their future activities. Details on the various studies that lie back of this bulletin are available in the files of the Southern District office of the Department of Water Resources.

William R. Gianelli

William R. Gianelli, Director
Department of Water Resources
The Resources Agency
State of California

State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES

RONALD REAGAN, Governor
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*** In charge of hydrologic phase and development of mathematical model

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## ABSTRACT

The water demand of the Raymond Basin Area was 52,000 acre-feet in 1970 and is expected to increase to approximately 70,000 acre-feet by 2020. / One of the most significant sources of water is the ground water basin in the area, which is being managed by a watermaster pursuant to a court decision. Approximately 1 million acre-feet of water was in storage in the basin in 1970. Net future replenishment under mean hydrologic conditions is estimated to be 24,600 acre-feet per year. In addition, the basin can be used as a reservoir for storing imported water for later use. / The bulletin summarizes the geologic and hydrologic data developed in the investigation and presents physical and economic information for four alternative plans for conjunctive use of ground and surface water resources to meet the future water demand.

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## ACKNOWLEDGMENTS

The Department of Water Resources acknowledges the information, advice and assistance given by the Raymond Basin Study Advisory Committee during the investigation. The Committee was consulted on significant items in the investigation at a series of meetings held from September 1968 to December 1970.

Raymond Basin Study Advisory Committee

| | |
|---|---|
| Mr. John L. Behner* | City of Pasadena |
| Mr. Karl A. Johnson | City of Pasadena |
| Mr. E. D. Richards | Valley Water Company and Foothill Municipal Water District |
| Mr. Tom H. Stauffer | Los Angeles County Flood Control District |
| Mr. Linn E. Magoffin | California-American Water Company |
| Mr. John A. Grivich | City of Arcadia |
| Mr. Bernard P. Westkamper | City of Sierra Madre |

The following were also in attendance at the meetings and provided valuable assistance:

| | |
|---|---|
| Mr. Carlos Madrid | Department of Water Resources, Deputy Watermaster |
| Mr. Thomas K. Underbrink | City of Pasadena |
| Mr. Willard O. Bangham | City of Pasadena |
| Mr. Anderson B. Smedley | Member, Board of Directors, The Metropolitan Water District of Southern California, representing Foothill Municipal Water District |
| Mr. Edward J. Zielbauer | Los Angeles County Flood Control District |
| Mr. Larry C. Bevington | City of Sierra Madre |

Special assistance on the hydrologic phase of the investigation was contributed by the City of Pasadena Water and Power Department.

| | |
|---|---|
| Mr. Thomas K. Underbrink | City of Pasadena |
| Mr. Chang Joon Kim | City of Pasadena |
| Mr. Michael L. Sheehy | City of Pasadena |

Also contributing information and advice were the following agencies:

Federal Agencies

United States Geological Survey,
Water Resources Division

State Agencies

Water Resources Control Board
Department of Public Works, Division of Highways,
District VII

Los Angeles County Agencies

Flood Control District
Regional Planning Commission

Special Districts

La Cañada Irrigation District
Kinneola Irrigation District
San Gabriel County Water District

City Water Departments

Pasadena
Arcadia
Sierra Madre
San Marino
Alhambra

Other Agencies

Las Flores Water Company
Lincoln Avenue Water Company
Rubio Canon Land and Water Association
Valley Water Company
California-American Water Company
Canyon Mutual Water Company
East Pasadena Water Company
Huntington Library and Art Gallery
Mira Loma Mutual Water Company
Osborn Constructors
Royal Laundry and Dry Cleaning Company
Sunny Slope Water Company

* Upon the retirement of Mr. Behner as General Manager of the City of Pasadena Water and Power Department on June 29, 1970, he was succeeded by Mr. James T. Brodie.

## CONCEPTS UNDERLYING WATER PLANNING

Water is a commodity that meets basic human needs; without it, life cannot continue. This fact has made us somewhat emotional about water and we have come to treat water differently from other commodities.

However, water is an ever present commodity. It cannot be destroyed; it is used and then it returns to be used again. Water is around us in many forms. By means of treatment and timely delivery, which may be either expensive or inexpensive, this water can be put to all uses to meet our needs any place on earth. It is, then, not difficult to conclude that all the water demand of any area, now and in the future, can be met with proper planning.

Elements of Planning. An analogy between financial planning and water resources planning will help to identify the elements to be considered.

Figure 1 represents the components that are considered in family financial planning. To ensure sound financial planning, a complete inventory must be taken of the supply of money in terms of annual income,-assets, and borrowing capabilities, as well as an inventory of financial obligations. For financially advantageous decision-making, various alternative ways of meeting financial obligations and of increasing income must be considered very carefully. Only after a full evaluation of the advantages and limitations of various alternatives should a plan be selected and implemented.

Figure 2 represents the analogous components of water resources planning. This process involves:

1. Inventory of demand, supply and associated facilities.

2. Formulation of alternative plans for meeting demand.

3. Evaluation of advantages and limitations of alternatives.

4. Selection of a plan.

5. Implementation of the selected plan.

Figure 1: FINANCIAL MANAGEMENT PLANNING

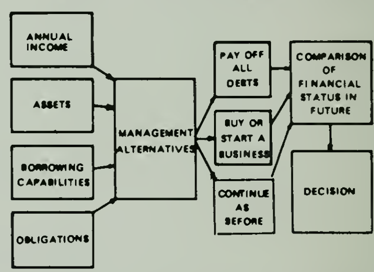
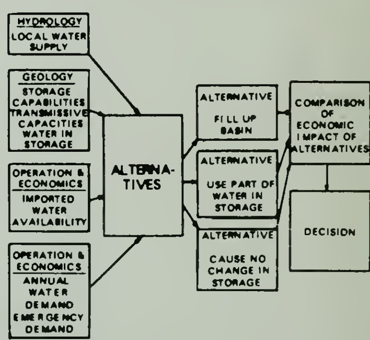



Figure 2 WATER MANAGEMENT PLANNING



# Chapter I: INTRODUCTION

The objective of the investigation reported here was to provide, for local agencies in the Raymond Basin Area, information on a wide range of alternative plans for managing their ground water supplies in coordination with their surface water supplies and facilities. With such information, managers of the local agencies will be in a position to make an informed selection of the most suitable plan.

The need for such comprehensive planning arises from the increasing demand for water and the increasing cost of obtaining it. Essential to this planning are the collection and analysis of data on water demand and supply, especially on the ground water supply which forms one of the most readily available sources in the Raymond Basin Area.

Accordingly, the Department of Water Resources, in cooperation with local agencies, has made this investigation. The findings are summarized in this report.

Detailed information on the geohydrology was printed in the form of technical information records (TIR), which were provided to members of the Advisory Committee during the study and are available in the files of the Southern District office of the Department of Water Resources.

## Area of Investigation

The Raymond Basin Area, shown on Plate 1 (page 28), is located immediately northeast of the City of Los Angeles and lies within the northwesterly portion of the San Gabriel Valley.

The alluvial valley floor of the study area contains approximately 40 square miles. It slopes to the south with elevations ranging from 2,000 feet above sea level at the mountain toe to 500 to 700 feet at the Raymond fault.

This area is highly urbanized and within it, wholly or partially, are found the cities of Pasadena, Sierra Madre, South Pasadena, San Marino, and Arcadia and the communities of La Canada and Altadena.

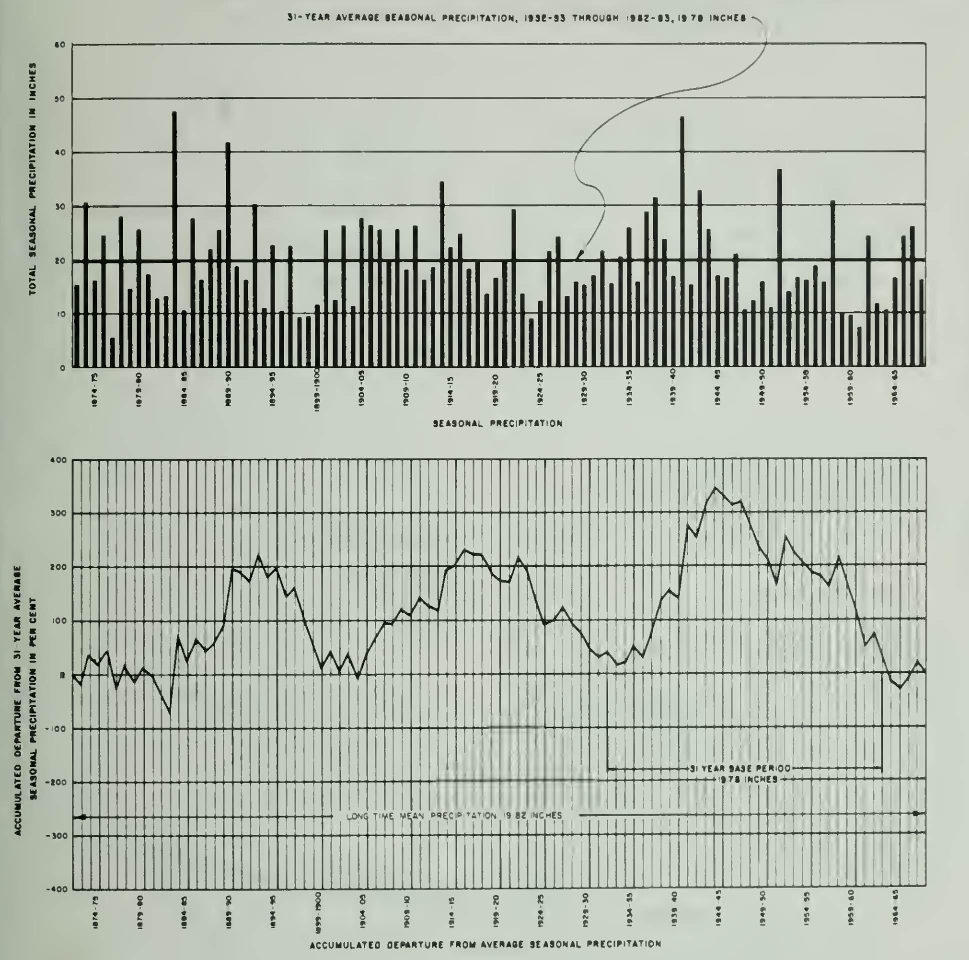
Three major hydrologic subdivisions lie within the area as shown on Plate 1: Monk Hill Basin, Pasadena Subarea, and Santa Anita Subarea. The lines of demarcation between the subdivisions, although somewhat arbitrary, represent general locations of ground water cascades or divides and thus essentially define ground water subbasins within the area (Plate 1).

The entire area lies within the watershed of the Los Angeles River. Surface runoff from San Gabriel Mountains enters the area through numerous streams, principally Arroyo Seco, Eaton Wash, and Santa Anita Wash. About one-third of the inflow is conveyed by Arroyo Seco, largest of the streams, which flows across Monk Hill Basin and Pasadena Subarea and joins Los Angeles River by cutting through San Rafael Hills. Outflow from the extreme westerly portion of Monk Hill Basin reaches Los Angeles River via Verdugo Wash. All other surface outflow enters the Rio Hondo. During periods of flood flows, some water may enter the San Gabriel River from the pool impounded behind Whittier Narrows Dam.

The Raymond Basin Area enjoys a semiarid, Mediterranean climate, characterized by warm, dry summers and mild winters with intermittent rain. About three-fourths of the annual precipitation occurs in the four months December through March.

Ambassador College, Pasadena

Figure 3 - PRECIPITATION CHARACTERISTICS AT PASADENA




The hydrologic conditions of 1932-33 through 1962-63 are considered to have been similar to the long-term mean hydrologic conditions of the area. Therefore, this period is referred to as the base period in this report. During the base period, the average annual depth of precipitation on the valley floor was 19.79 inches compared to the long-time average of 19.82 inches per year. To show how the base period average compares with the long-term average, Figure 3 gives the precipitation for one station within the study area.

**Figure 4 – WATER SUPPLY, USE, AND DISPOSAL OF THE GROUND WATER BASIN AS A FREE BODY IN RAYMOND BASIN DURING 1932–33 THROUGH 1962–63**

(SUPPLY)

During the base period the approximate average water supply to the basin was about 79,500 acre-feet a year. Of this amount:

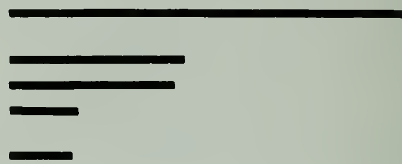
Precipitation falling on the basin surface amounted to . . . . . . . . . . . . . . 36,100 acre-feet

Surface inflow in streams and from tributary mountains and hills . . . . . . . 15,900 acre-feet

Fresh water imports . . . . . . . . . . . . 14,900 acre-feet

Subsurface inflow . . . . . . . . . . . . 6,500 acre-feet

Surface water diverted into the basin from the nonwater-bearing areas. . . . . . 6,100 acre-feet



(USE and DISPOSAL)

The approximate yearly use and disposal amounted to 80,600 acre-feet. Of this amount:

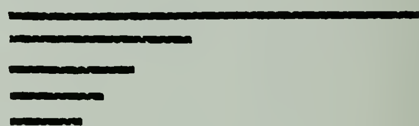
Total consumptive use amounted to . . . . 38,100 acre-feet

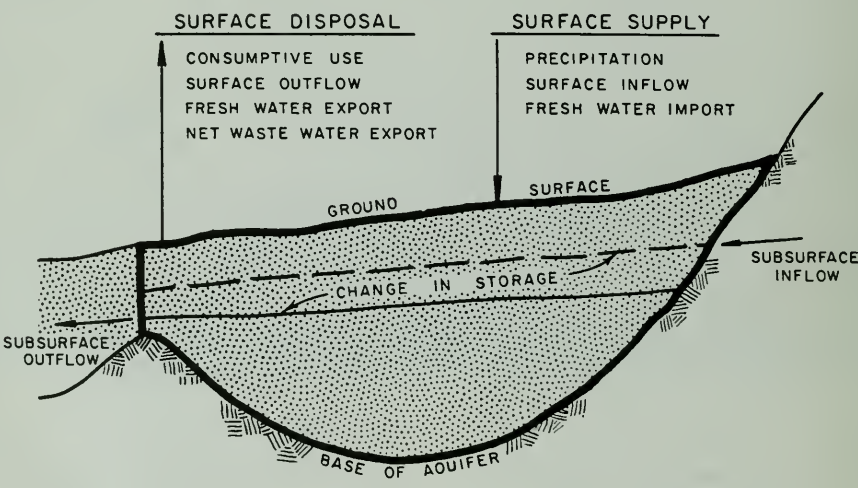
Surface outflow in streams. . . . . . . . 16,600 acre-feet

Waste water exports . . . . . . . . . . . 11,100 acre-feet

Fresh water exports . . . . . . . . . . . 8,400 acre-feet

Subsurface outflow . . . . . . . . . . . 6,400 acre-feet






THE GROUND WATER BASIN AS A FREE BODY

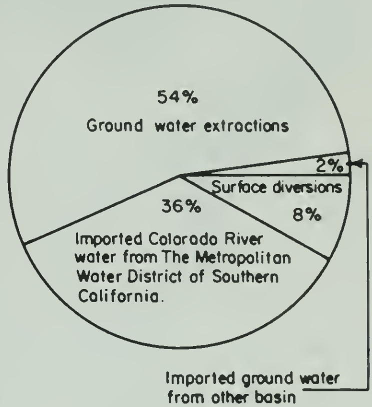
The earliest known development of a water supply in the Raymond Basin Area was at San Gabriel Mission, founded in 1771 by Fra Junipero Serra in what is now the City of San Gabriel and entirely outside the study area. The site was chosen for the mission because of the easily diverted streams which flowed from the cienegas caused by the Raymond fault.

Further development may have occurred gradually in the following years, but larger developments of water supplies did not begin until a century later when the great influx of population to Southern California began. The supplies developed included not only the flows from just above the Raymond fault, but also the small discharges of the streams issuing from the mountains and various springs along Arroyo Seco.

The surface supplies were the first to be used. Next, tunneling in the vicinity of the surface supplies was resorted to. Finally, wells were constructed. The first wells, constructed as early as 1881, are believed to have been drilled in the marshy area above the Raymond fault; these produced artesian flows which later ceased because of lowered pressure. Wells were also drilled near Devils Gate. Drilling gradually extended outward from the original points of discovery.

Information on the mean water supply and disposal in this area during the base period is summarized in Figure 4 and the breakdown of the sources of water used to meet the demand of the area is shown in Figure 5.

Figure 5-COMPARATIVE MAGNITUDE OF SUPPLY IN THE RAYMOND BASIN AREA, 1961-1969 NINE-YEAR AVERAGE




*SOURCES OF WATER TO MEET DEMAND*

## Conduct of Investigation

The work program for this investigation was divided into three phases: geology, hydrology, and operation-economics. The first two phases were designed to develop information related to the locally available water supplies and information on the characteristics of the ground water basin. A mathematical model of the basin was formulated so that future fluctuations in water levels could be simulated under various physically possible plans of operation. The information thus developed was used in the operational-economic phase of the investigation in which the cost of water service under the alternative plans of operation was estimated.

So that a more comprehensive evaluation of the physical effects of the alternative plans might be made, the study area was divided into 79 polygonal subareas called nodes. This division was governed primarily by the region's geohydrologic characteristics; the number of nodes was determined by the availability of data, the cost, and the extent of information desired.

For ease of handling, the study area was also subdivided into eight opera-

Figure 6: OPERATIONAL AREAS

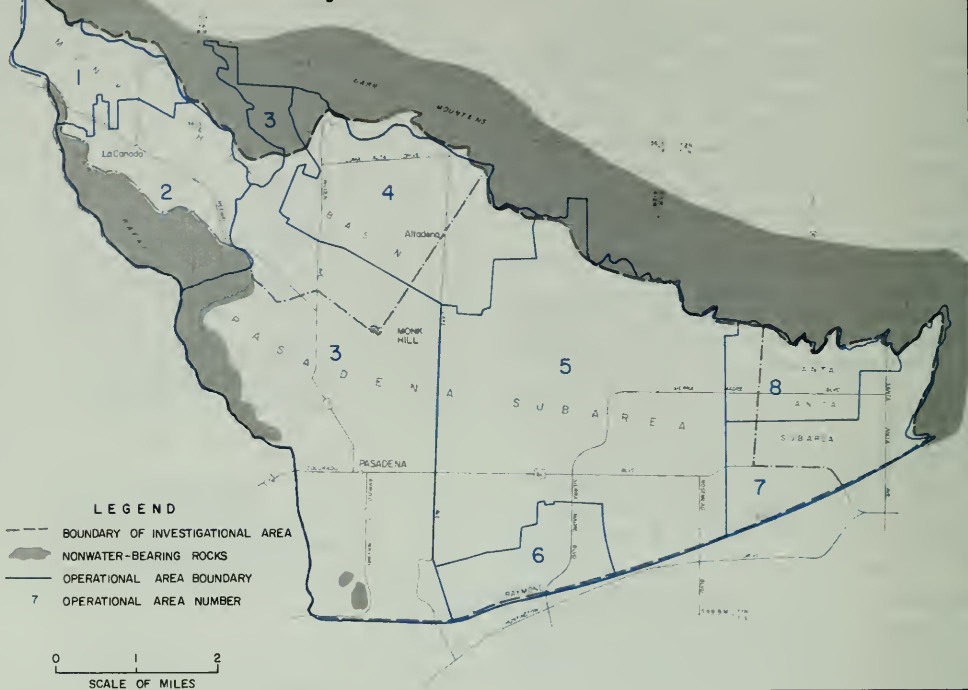
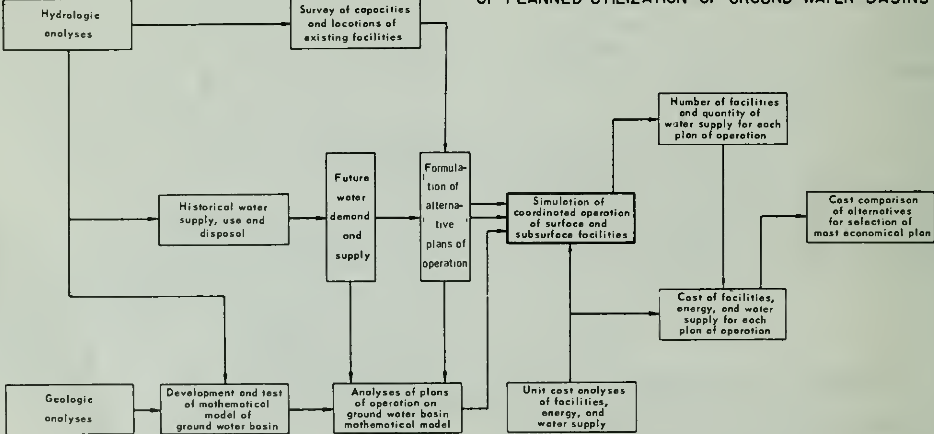



Figure 7 SIMPLIFIED FLOW CHART OF INVESTIGATION OF PLANNED UTILIZATION OF GROUND WATER BASINS



tional areas (Figure 6). Their boundaries were based primarily on the boundaries of the water districts and service agencies and partially on present and future land use and geology.

The general steps employed in this study are represented schematically on a simplified flow chart in Figure 7. The chart indicates the sequence of contributory studies and their relationship to the overall investigation.

The heavily outlined block represents the simulation of the coordinated operation of surface and ground water facilities. At this point, the alternative plans were analyzed and the results integrated with the cost of facilities, energy, and water supply for each. Thus, the costs for the alternative plans could be compared.

This investigation dealt with the future water service in the study area. Therefore, a number of factors affecting the supply of water and the cost of water service could not be predicted conclusively. Some factors were assumed to stay the same as they were in 1970, the beginning year of the operation-economics phase of the investigation. For other factors, conditions that might develop in the future had to be assumed.

In the study of the alternative plans of basin operation, all water supplies--including ground water in storage--received full consideration. Thus, a wide range of alternative plans of basin operation, in coordination with other water supplies and facilities, were evaluated operationally and economically, on the premise that all legal, political, and organizational obstacles or limitations can be surmounted. Nonetheless, these factors, which are beyond the scope of this report, will have to be considered by local agencies in selecting a plan.

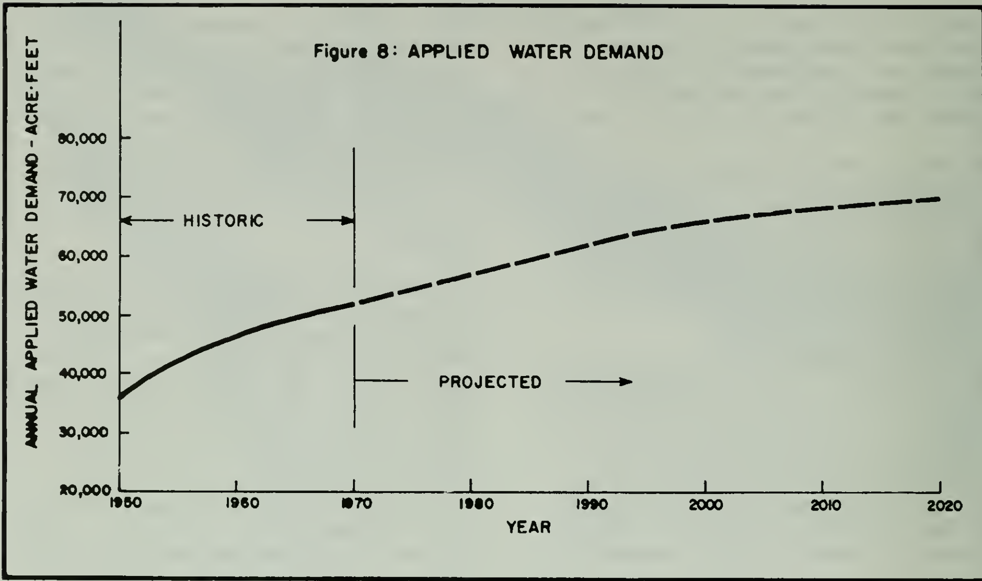


Figure 8: APPLIED WATER DEMAND
ANNUAL APPLIED WATER DEMAND - ACRE·FEET
80,000
70,000
60,000
50,000
40,000
30,000
20,000
HISTORIC
PROJECTED
1950
1960
1970
1980
1990
2000
2010
2020
YEAR

# Chapter II: INVENTORY OF WATER DEMAND, SUPPLY, AND QUALITY

The first requirement for effective planning to manage the water resources of an area is to know the size and type of demand and the size and quality of the available supplies.

## Water Demand

Water is needed to satisfy the demand within the area and to meet the area's legal obligation to pumpers exporting ground water.

### Within Area

The total demand for water in the area consists of demand for delivered water for domestic and industrial uses. Agricultural land use and livestock population are negligible in this highly urbanized area.

The water demand of this area is approximately 52,000 acre-feet in 1970 and is expected to grow to about 70,000 acre-feet in 2020 as shown on Figure 8.

The demand for delivered water for each of the eight operational areas depicted in Table 1 was determined for the study period 1970-2020 (calendar years). The estimated future demand was obtained by multiplying projected per capita water use figures by projected population. The projected per capita water use reflects increases in future water prices.

### To Meet Legal Obligations

The first application of the California Water Code Court Reference procedure to ground water was initiated in the Raymond Basin. The City of Pasadena filed suit in 1937 to quiet title to ground water rights within the basin (City of Pasadena v. City of Alhambra, et al. Los Angeles County Superior Court No. Pasadena C-1323, 33 Cal 2d 908, 207 P. 2d 17 [1949]). The court in 1939 appointed the Division of Water Resources (forerunner of Department of Water Resources) to referee the case and requested a determination of the safe yield of the basin. The Report of Referee, which was filed in 1943, indicated an annual decreed right safe yield of 21,900 acre-feet. The following year the court approved the official judgment which required that ground water extractions from the Raymond Basin subareas be limited to their decreed right safe yield.

Prior to entry of the judgment, the court had approved a water exchange agreement. The agreement allows parties signatory thereto to meet their demands for water in excess of their decreed right and supplementary water supply by obtaining water from an exchange pool offered by other signatory parties and administered by the Watermaster on an annual basis.

Table 1: DELIVERED WATER DEMAND COMPARED WITH POPULATION
1970-2020

| Area | Year | | | | | |
|---|---|---|---|---|---|---|
| | 1970 | 1980 | 1990 | 2000 | 2010 | 2020 |
| Operational | Delivered Water Demand, in thousands of acre-feet | | | | | |
| 1 | 1.9 | 2.0 | 2.0 | 2.1 | 2.1 | 2.2 |
| 2 | 2.5 | 2.8 | 2.9 | 3.0 | 3.1 | 3.2 |
| 3 | 16.0 | 17.9 | 19.4 | 20.3 | 20.8 | 21.2 |
| 4 | 6.4 | 7.0 | 7.4 | 7.8 | 8.0 | 8.2 |
| 5 | 15.4 | 17.0 | 18.2 | 19.0 | 19.5 | 19.8 |
| 6 | 2.1 | 2.3 | 2.5 | 2.6 | 2.7 | 2.8 |
| 7 | 4.7 | 5.6 | 6.5 | 7.4 | 8.1 | 8.6 |
| 8 | 2.7 | 3.0 | 3.4 | 3.6 | 3.8 | 3.9 |
| Total | 51.7 | 57.6 | 62.3 | 65.8 | 68.1 | 69.9 |
| Raymond Basin | Population, in thousands | | | | | |
| Total | 230 | 247 | 260 | 268 | 273 | 276 |

In 1944, the Raymond Basin Watermaster Service Area was created pursuant to the California Water Code. After six successful years of watermaster service, the court approved a motion by the City of Pasadena to redetermine the decreed right safe yield. The new decreed right safe yield was calculated to be greater than originally determined: nearly 31,000 acre-feet per year. A "Modification of Judgment" increased the proportionate decreed rights of each party to the new decreed right safe yield in 1955. Included in the decreed rights of certain parties are amounts of ground water being exported from this area.

In summary, the Raymond Basin Judgment limits the amount of water that each party can extract or divert and ratifies the water exchange pool.

## Water Supply

In the nine years of 1961 through 1969, water service agencies pumped an average of 30,000 acre-feet per year, of which about 5,200 acre-feet was exported. Water supplies to meet the demand in the study area consist primarily of locally pumped ground water (54 percent) and imported Colorado River water (36 percent).

Although imported ground water from other basins amounted to 2 percent during this period, for this study none was considered.

### Imported Water

Supplying Colorado River water to this area is The Metropolitan Water District of Southern California (MWD). Among

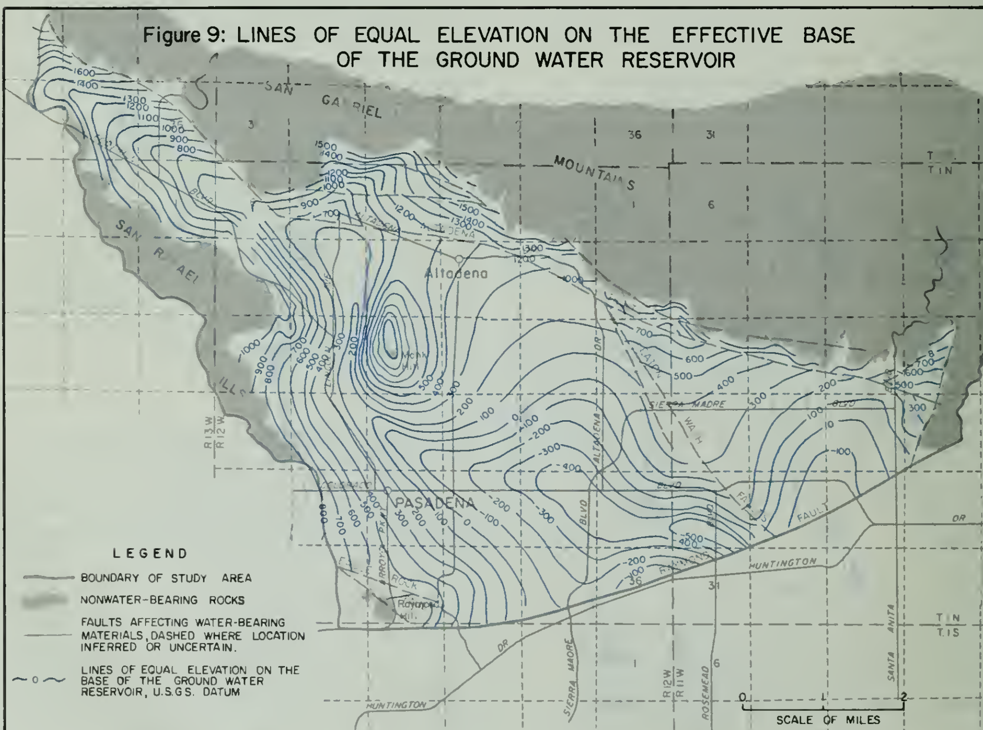



Figure 9: LINES OF EQUAL ELEVATION ON THE EFFECTIVE BASE OF THE GROUND WATER RESERVOIR

its member agencies are the cities of Pasadena and San Marino; Foothill Municipal Water District which includes all the Monk Hill Basin except that portion of the City of Pasadena that lies within this basin and Kinneola Irrigation District; and the Upper San Gabriel Valley Municipal Water District, of which the City of Arcadia is a member.

Of these member agencies, the City of Arcadia has not used the imported water and the City of San Marino has not used significant amounts; however, such water is available should an emergency occur.

MWD has announced plans for construction of a Foothill Feeder to be used to supply State Water Project water to the Raymond Basin Area beginning in 1986. However, at the time this study was made, the first deliveries were scheduled for 1978; therefore, this study is based on the earlier date. This change does not appreciably affect the relative economics of the alternative plans nor the validity of the study.

In addition, the City of Sierra Madre is a member of the San Gabriel Valley Municipal Water District, which has contracted with the State of California for supplemental water to be delivered via the Santa Ana Division of the California Aqueduct (first delivery in 1973, with a maximum entitlement of 28,800 acre-feet per year).

## Local Surface and Waste Water

The major source of surface water is the runoff from the San Gabriel Mountains. During the base period, the average annual amount of diverted surface water used locally for direct use was 4,160 acre-feet.

In recent years, the sewerage systems have expanded to such a degree that, for this study, all waste water is considered to be exported from the study area. The La Canada area has septic tanks but represents only a small portion of the total sewage production. The Los Angeles County Sanitation District has no present plans for waste water reclamation in the study area.

## Local Ground Water

To estimate the supply potential of ground water, the amount of ground water currently in storage, the replenishment, and the allowable reduction of the ground water in storage must be determined.

Water in Storage. The area consists mainly of unconsolidated sediments, or alluvium, deposited by streams flowing from the mountain. Ground water is stored within the interstices of these unconsolidated sediments.

Crystalline bedrock generally forms tne base under the alluvium all along the western and northern sides of the Raymond Basin. Elsewhere, the base has been fixed at the top of essentially impermeable sediments.

Crystalline bedrock and impermeable sediments are considered nonwater bearing. The classification of a group of rocks or sediments as nonwater bearing does not mean that they contain no water, but rather, as defined for use in this report, that they yield water to wells at a rate of less than 100 gallons per minute for sustained periods. Locally, pervious strata or fracture zones may yield water freely to wells, but generally such production is limited and recharge is usually inadequate for long-term production.

A contour map of the base of the water-bearing material is presented in Figure 9. As it shows, the elevation of the base ranges from over 1,600 feet above sea level to more than 500 feet below sea level.

Not all water in the aquifers can be extracted. Even when an aquifer is

Table 2: ZONE OF SATURATION: INFLOW AND OUTFLOW COMMON TO ALL PLANS OF OPERATION 1970-2020

| Item | Amount, in 1,000 acre-feet per year | |
|---|---|---|
| I. Inflow (Estimated) | | |
| A. Deep percolation | | |
| 1. Precipitation | 9.0 | |
| 2. Delivered water | 7.5 | |
| 3. Streamflow | 3.5 | |
| 4. Local spread | 3.1 | |
| B. Subsurface flow | 7.9 | |
| C. Total | | 31.0 |
| II. Outflow (Estimated) | | |
| A. Exported ground water | 5.2 | |
| B. Subsurface flow | 6.4 | |
| C. Total | | 11.6 |
| Net inflow | | 19.4 |

* Under water supply conditions of historic mean precipitation.

supposedly pumped "dry", a small amount of water remains as a thin film coating the particles of sand and gravel. Hence, as employed by hydrologists, the word "storage" refers only to the actual amount of water than can be extracted from sediments.

The percentage of water that is still retained as a thin film around the individual sediment particles is technically termed "specific retention". On the other hand, the ratio of the volume of water that can be removed by gravity drainage to the total volume of saturated sediment is technically termed "specific yield".

In the study area, the specific yield of the water-bearing materials was estimated at from 3 percent for the fine materials (clay) to as high as 35 percent for the coarse material (medium sand). To calculate the total amount of water in storage, the specific yield was multiplied by the volume of the saturated aquifers. Thus, the volume of ground water stored in the valley was estimated to be one million acre-feet in 1970. Total storage capacity (20 feet from ground surface to base of aquifer) is about 1,450,000 acre-feet.

Replenishment. The ground water basin is replenished by subsurface inflow and by deep percolation of water from various sources. These sources are precipitation and resulting runoff, delivered water, and water spread in streambeds and spreading grounds (see Table 2).

Deep percolation of precipitation occurs both inside and outside of streambeds. The deep percolation of precipitation was estimated to be about 12,500 acre-feet per year on the average under mean precipitation conditions (Items 1 and 3 under "Deep Percolation" in Table 2).

Deep percolation from delivered water results from irrigation of lawns, gardens, and other areas. Under today's cultural conditions, with a mean annual precipitation, deep percolation from irrigation is estimated to be 7,500 acre-feet.

The Los Angeles County Flood Control District and the City of Sierra Madre operate and maintain spreading grounds throughout the Raymond Basin Area (see Plate 1). The average yearly amount of native water conserved is about 3,100 acre-feet.

This ground water basin also receives subsurface inflow from watersheds that front the northern and western sides of the basin. Most of the precipitation falls on the mountains and highlands; much of it runs off the surface of the impervious rocks into canyons that drain toward the valley, but a portion finds its way into fractures and joints, and eventually flows into the valley-filling alluvium as frontal flow from bedrock. In addition, some of the surface runoff in the larger canyons is absorbed into the alluvium in them and migrates in the subsurface to the central ground water body.

Arroyo Seco Canyon

Removal. Ground water is removed by subsurface outflow and by pumping. Historically, the subsurface outflow from the valley occurred through the Raymond fault. This amounted to an annual average of 6,370 acre-feet during the base period. In 1961-69, about 54 percent of the demand of the area for delivered water was met by water pumped from the ground water basin. In the future, the amount of water to be pumped from the basin will depend upon the plan of operation that is implemented. It was assumed that 5200 acre-feet per year of ground water would be exported by pumpers as provided by the decree. Thus, the net future replenishment (under mean hydrologic conditions) is 24,600 acre-feet per year.

## Quality of Water Supply

Water quality is a result of both natural phenomena and manmade changes in the water environment. Virtually all activities of man or nature will alter the quality of water used. Therefore, both quantity and quality of water resources must be considered in planning for their full beneficial use.

### Imported Water

Water from the State Water Project generally will contain less total dissolved solids (TDS) and will be softer than is local water. Quality objectives for Northern California water delivered to MWD and the San Gabriel Valley Municipal

Table 3: WATER QUALITY OBJECTIVES FOR IMPORTED STATE WATER*

| Item | | Average | |
|---|---|---|---|
| Name | Symbol | Monthly | Any 10-Years |
| | | (Milligrams per Liter) | |
| Sulfate | $SO_4$ | 110 | 20 |
| Chloride | Cl | 110 | 55 |
| Total Dissolved Solids | TDS | 440 | 220 |
| Total Hardness as | $CaCO_3$ | 180 | 110 |
| | | (Percent) | |
| Sodium Percentage | Na% | 50 | 40 |
| | | Maximum | |
| | | (Milligrams per Liter) | |
| Phenol | - | 0.001 | |
| Arsenic | As | 0.05 | |
| Hexavalent Chromium | $Cr^{+6}$ | 0.05 | |
| Selenium | Se | 0.05 | |
| Lead | Pb | 0.1 | |
| Iron and Manganese | Fe&Mn | 0.3 | |
| Fluoride | F | 1.5 | |
| Copper | Cu | 3.0 | |
| Zinc | Zn | 15.0 | |
| Magnesium | Mg | 125.0 | |

* Adapted from Bulletin No. 141, "The California State Water Project Water Supply Contracts", California Department of Water Resources, November 1965. Volume I, page 600.

Water District are set forth in Table 3. The estimate provided is of water quality after the Peripheral Canal is operational.

Filtered and softened Colorado River water, purchased from MWD, is available to the member agencies in this area. Table 4 provides representative historic and recent mineral analyses of this water and a recent analysis of the natural, untreated Colorado River water. Natural Colorado River water is of sodium - calcium sulfate character and is very hard.

## Local Surface Water

As has been pointed out, diverted surface water constitutes an important part of the water supply in the study area. Table 5 presents representative historic mineral analyses of this water. Data for Arroyo Seco and Eaton Canyon Wash indicate that the change of

Tables 4 and 5: SURFACE WATER ANALYSIS

Table 4: COLORADO RIVER WATER, by Year

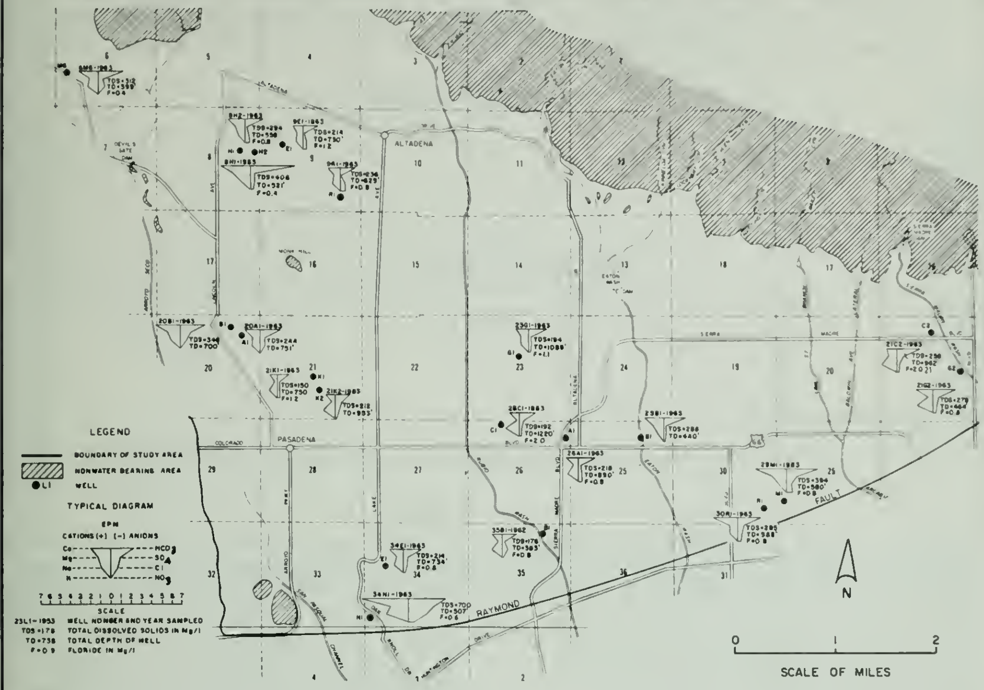
| Item | | Softened and Filtered | | | | Natural | |
|---|---|---|---|---|---|---|---|
| Name | Symbol | 1952-53 | 1962-63 | 1967-68 | 1968-69 | 1967-68 | 1968-69 |
| | | pH Scale | | | | | |
| Hydrogen Ion Concentration | pH | 8.53 | 8.15 | 8.40 | 8.40 | 8.3 | 8.4 |
| | | Micromhos at 25° Celsius | | | | | |
| Electrical Conductivity | $ECx10^6$ | - | - | 1195 | 1220 | 1105 | 1140 |
| | | Milligrams per Liter | | | | | |
| Calcium | Ca | 31.9 | 55.8 | 31.0 | 34.0 | 82 | 84 |
| Magnesium | Mg | 11.6 | 18.8 | 12.0 | 14.0 | 30.5 | 31.0 |
| Sodium | Na | 186 | 168 | 199 | 201 | 103 | 108 |
| Sodium and Potassium | Na&K | | | | | | |
| Potassium | K | - | - | 5 | 4 | 5 | 5 |
| Carbonate | $CO_3$ | 5.2 | 0.0 | 2.0 | 2.0 | 1 | 1 |
| Bicarbonate | $HCO_3$ | 134 | 151 | 140 | 143 | 143 | 145 |
| Sulfate | $SO_4$ | 275 | 303 | 298 | 307 | 298 | 307 |
| Chloride | Cl | 93 | 101 | 98 | 102 | 93 | 98 |
| Nitrate | $NO_3$ | - | - | 0.6 | 1.0 | 0.7 | 1.1 |
| Fluoride | F | 0.50 | 0.42 | 0.4 | 0.4 | 0.4 | 0.4 |
| Iron | Fe | | | | | | |
| Boron | B | - | - | 0.11 | 0.10 | 0.11 | 0.10 |
| Silica | $SiO_2$ | 7.8 | 10.3 | - | 8.5 | 8.7 | 8.7 |
| Total Dissolved Solids | TDS | 678 | 749 | 725 | 746 | 694 | 717 |
| Total Hardness as | $CaCO_3$ | 128 | 216 | 127 | 142 | 330 | 337 |
| Alkalinity as | $CaCO_3$ | | | | | | |
| | | Percent | | | | | |
| Sodium Percentage | Na% | 76 | 63 | 78 | 76 | 40 | 41 |

Table 5: RAYMOND BASIN WATERS, by Source and Year

| Item | | Arroyo Seco | | | Eaton Canyon Wash | | | El Prieto Canyon | | Rubio Canyon | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | Symbol | 1952-53* | 1962-63* | 1970 | 1952-53* | 1962-63* | 1970 | 1959 | 1970 | 1955 | 1970 |
| Hydrogen Ion Concentration | pH | | | | | | | | | | |
| Electrical Conductivity | $ECx10^6$ | | | | | | | | | | |
| | | Milligrams per Liter | | | | | | | | | |
| Calcium | Ca | 51.2 | 55.8 | 47.0 | 41.0 | 45.3 | 35.2 | 46.0 | 52.0 | 45.0 | 29.0 |
| Magnesium | Mg | 17.1 | 18.1 | 18.0 | 14.0 | 16.2 | 10.7 | 18.0 | 15.0 | 11.0 | 6.0 |
| Sodium | Na | | | | | | | | | | |
| Sodium and Potassium | Na&K | 21.3 | 22.1 | 23.7 | 12.7 | 12.8 | 8.0 | 19.0 | 19.1 | 17.0 | 23.0 |
| Potassium | K | | | | | | | | | | |
| Carbonate | $CO_3$ | 0.0 | 0.2 | 0.0 | 5.6 | 4.3 | 0.0 | - | - | - | - |
| Bicarbonate | $HCO_3$ | 244 | 268 | 225 | 188 | 197 | 128 | - | 223 | - | 109 |
| Sulfate | $SO_4$ | 31.4 | 27.3 | 30.0 | 17.5 | 24.2 | 24.0 | 43.0 | 26.0 | 23.0 | 7.0 |
| Chloride | Cl | 11.5 | 12.1 | 14.0 | 8.5 | 8.8 | 6.2 | 8.0 | 9.0 | 10.0 | 17.0 |
| Nitrate | $NO_3$ | | | | | | | | | | |
| Fluoride | F | 0.6 | 0.5 | 0.8 | 0.6 | 0.7 | 1.2 | 0.3 | 1.2 | 2.0 | 1.0 |
| Iron | Fe | 0.11 | 0.30 | - | 0.04 | 0.03 | 0.00 | 0.20 | - | 0.1 | - |
| Boron | B | | | | | | | | | | |
| Silica | $SiO_2$ | 24.8 | 27.1 | 21.0 | 21.2 | 20.2 | 16.4 | - | - | - | - |
| Total Dissolved Solids | TDS | 280** | 296** | 268** | 216** | 226 | 170 | 280 | 254 | 291 | 221 |
| Total Hardness as | $CaCO_3$ | 198 | 213 | 190 | 162 | 180 | 132 | 190 | 191 | 159 | 98 |
| Alkalinity as | $CaCO_3$ | 200 | 220 | 184 | 163 | 169 | 105 | 171 | 183 | 149 | 89 |
| | | Percent | | | | | | | | | |
| Sodium Percentage | Na% | 19 | 19 | 21 | 14 | 14 | 12 | 18 | 17 | 19 | 48 |

* Average values for a water year
** Value calculated by using half of the $HCO_3$ and all other constituents

Figure 10: STIFF DIAGRAMS OF GROUND WATER QUALITY SAMPLE PERIOD 1962-1963




quality with time is insignificant and is mainly dependent on the quantity of flow. The water is calcium bicarbonate in character and is moderately hard to hard.

## Local Ground Water

The quality of the ground water is the result of complex physical, biological, and chemical reactions while the water is infiltrating the soil zone and unsaturated zone and is moving in the saturated zone. These reactions include solution, precipitation (controlled by the solubility of minerals), oxidation, reduction (due to lack or abundance of oxygen or to biological factors), ion exchange, and filtration.

In addition to the natural effects of the geologic environment, human activities also have significant effects on water quality. By using and reusing water for domestic, industrial, or agricultural purposes, man discharges liquid or solid wastes into the geologic environment. This, in turn, affects and degrades the quality of both surface and ground water, which is constantly being changed because of the continual replenishment of the basin by new or recycled water.

The 1962-63 ground water quality data are shown on Figure 10. TDS values ranged from 150 mg/l in well 1N/12W-21K1 to 700 mg/l in well 1N/12W-34N1, the average being 280 mg/l. Chemical character

## Tables 6 and 7: GROUND WATER ANALYSIS

| Item | | Concentration, in Milligrams per Liter | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Lowest | | | | | | | | | Highest | | | | | |
| Name | Symbol | Well 1N/11W- 11C4 | Well 1N/11W- 21C1 | Well 1N/11W- 21G5 | Well 1N/12W- 9R1 | Well 1N/12W- 13E2 | Well 1N/12W- 21K1 | Well 1N/12W- 25B1 | Well 1N/12W- 26C1 | Several Wells | Well 1N/11W- 21C2 | Well 1N/11W- 29M1 | Well 1N/12W- 6M6 | Well 1N/12W- 8H1 | Well 1N/12W- 26C1 | Well 1N/12W- 34N1 |
| **Table 6: FOR 1962-63** | | | | | | | | | | | | | | | | |
| Calcium | Ca | | | | | | 21 | | | | | | | | | 123 |
| Magnesium | Mg | | | | | | | | 4 | | | | | | | 27 |
| Sodium | Na | | | | | | | 12 | | | | | | | | 62 |
| Bicarbonate | $HCO_3$ | | | | | | 92 | | | | | | | 345 | | |
| Sulfate | $SO_4$ | | | | 5 | | | | | | | | | | | 156 |
| Chloride | Cl | | | | | 5 | | | | | | | | | | 85 |
| Nitrate | $NO_3$ | | | | | 2.5 | | | | | | | | | | 44 |
| Fluoride | Fl | | | | | | | | | Trace | 2.0 | | | | 2.0 | |
| Total Dissolved Solids | TDS | | | | | | 150 | | | | | | | | | 700 |
| Total Hardness as | $CaCO_3$ | | | | | | 73 | | | | | | | | | 418 |
| **Table 7: FOR 1963-64 THROUGH 1967-68** | | | | | | | | | | | | | | | | |
| Calcium | Ca | | | | 19 | | | | | | | 73 | | | | |
| Magnesium | Mg | | | 5 | | | | | | | | | | 28 | | |
| Sodium | Na | | | | | | | 12 | | | | | 193 | | | |
| Bicarbonate | $HCO_3$ | | | | | | 90 | | | | | | | 306 | | |
| Sulfate | $SO_4$ | | | | 3 | | | | | | | | 310 | | | |
| Chloride | Cl | | 11 | | | | | | | | | | 109 | | | |
| Nitrate | $NO_3$ | 7.3 | | | | | | | | | | 40 | | | | |
| Fluoride | Fl | | | | | | | | | Trace | | | | | 1.5 | |
| Total Dissolved Solids | TDS | | | | 170 | | | | | | | | 772 | | | |
| Total Hardness as | $CaCO_3$ | | | | | | | | 82 | | | | | 292 | | |

was largely calcium bicarbonate. Upper and lower limits of concentrations of the major ionic constituents in extracted ground water in 1962-63 are listed on Table 6. The water, as demonstrated by the maximum concentrations of mineral constituents, was still suitable for all beneficial uses. However, it ranged from soft to very hard and, in a few wells, contained fluoride in concentrations above those recommended for drinking.

The analyses of the basin's water quality is based on data obtained from 1963 through 1968. The use of 1963 data was necessary because data for 1968 alone were insufficient. Table 7 shows the present upper and lower limits of concentrations of the major ionic constituents in the ground water.

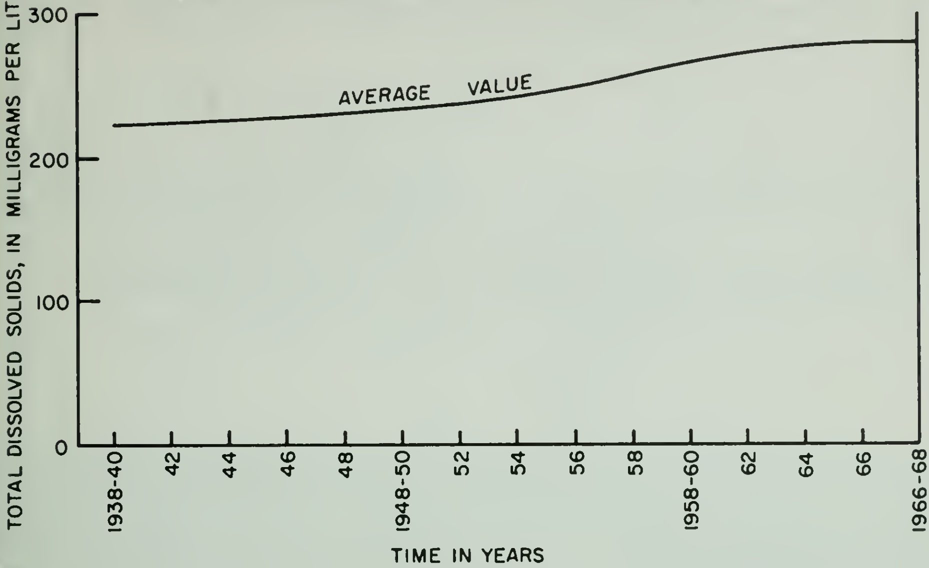
Except for a few wells where fluoride concentration is above 1.0 mg/l, the ground water extracted from the basin is of good mineral quality and suitable for prevailing beneficial uses. It ranges from soft to very hard.

A comparison of the present and historic data indicates that, in general, the change in water quality has been slight but trending toward an increase in TDS (Figure 11). However, there are cases of localized degradation of ground water quality as in the western portion of Monk Hill Basin and in the Devil's Gate area. The quality characteristics of the ground water reflect both the quality of the precipitation, which forms the basin's main source of recharge, and the chemical makeup of the aquifer sediments.

The area's proximity to the foothills of the San Gabriel Mountains, which provide considerable runoff for recharge; the presence of recharge basins for spreading surface runoff; and the export of most domestic and industrial wastes combine to reduce the possible degradation of the ground water quality.

With the spreading of water from the State Water Project, favorable effects on the quality should occur with time. However, the effects will be mostly local because of the slow rate of ground water movement.

Figure II: GROUND WATER QUALITY (TDS) WITH TIME



## Table 8: GROUND WATER RECHARGE (Historical)

| Spreading Grounds | Amounts | | | | Time | | | | Percolation Rate* (Short Term), in cubic feet per second | Capacity** (Maximum), in acre-feet per year |
|---|---|---|---|---|---|---|---|---|---|---|
| | Record, in years | Acre-feet per year | | | Record, in years | Days per year | | | | |
| | | Average | Maximum | Minimum | | Average | Maximum | Minimum | | |
| Arroyo Seco | 21 | 578 | 2,088 | 0 | 19 | 32 | 86 | 0 | 15 | 4,200 |
| Eaton Wash | 22 | 500 | 3,249 | 0 | 14 | 24 | 135 | 0 | 19 | 8,140 |
| Santa Anita | 25 | 427 | 1,641 | 0 | 24 | 39 | 158 | 0 | 7 | 3,000 |
| Sierra Madre | 18 | 1,538 | 5,003 | 43 | 13 | 48 | 190 | Record Incom-plete | 18 | 7,800 |
| TOTAL | - | 3,043 | 11,981 | - | - | 143 | 569 | - | 59 | 23,140 |

* The short term percolation rate is based on infiltration rates which may be expected to persist for at least five days but which are not valid for sustained spreading operations.

** The maximum anticipated annual recharge capacities are based on the assumption that aquifer water logging will not constitute a limitation on spreading capabilities. They include consideration for apreading grounds outages for maintenance and insect control required by year-long operation. Imported water would augment the local aupply from about October to April and would be the only source from about April to October.

Arroyo Seco Spreading Grounds

# Chapter III: INVENTORY OF FACILITIES

Essential to the study was an evaluation of the adequacy of existing and proposed water supply facilities within the study area to meet the projected demand.

## Ground Water Facilities

The ground water basin can be considered as a part of the network of storage and delivery facilities.

To illustrate, the rate of deep percolation and subsurface inflow into the ground water reservoir is equivalent to the rate of inflow into a surface reservoir. The storage capacity of the ground water basin is comparable to the storage capacity of a surface reservoir. The transmissive characteristics of the aquifers of the basin may be compared to the delivery characteristics of a surface distribution system. Finally, the ground water table in the basin is analogous to the hydraulic grade line elevation in a surface distribution system.

By using equations that numerically describe the flow characteristics of the ground water basin, one can calculate the capabilities of the basin as water delivery media. From this, one can determine the additional facilities required. This determination enables one to estimate the cost of water service under various plans of basin operation.

To integrate the ground water basin into the delivery system, a mathematical model of the basin was developed. It was used to estimate future ground water level elevations in various parts of the basin under alternative plans of basin operation.

When the ground water basin is regarded as part of the delivery system, streambeds and manmade spreading grounds are the initial point and wells are the terminal point. Information on the existing spreading grounds is given in Table 8. The maximum anticipated annual recharge capacity is 23,000 acre-feet.

A large number of wells are scattered throughout the valley. The distribution of these in 1969 is shown on Plate 1.

## Surface Water Facilities

The existing MWD Upper Feeder, as shown on Plate 1, supplies treated Colorado River water to this basin. The proposed MWD Foothill Feeder, as shown on Plate 1, is scheduled to transport State Water Project water to this basin in 1978*.

## Facilities Common to All Plans

Many of the water delivery facilities would be required no matter whether surface or ground water is used. This group includes small pipelines and the distribution systems owned and operated by both private and municipal agencies. These facilities were excluded from consideration because they are common to all plans of operation and do not affect the comparison of the cost of alternative plans.

*This was the date used for this study. After the study was completed, MWD announced that the delivery date had been moved to 1986.

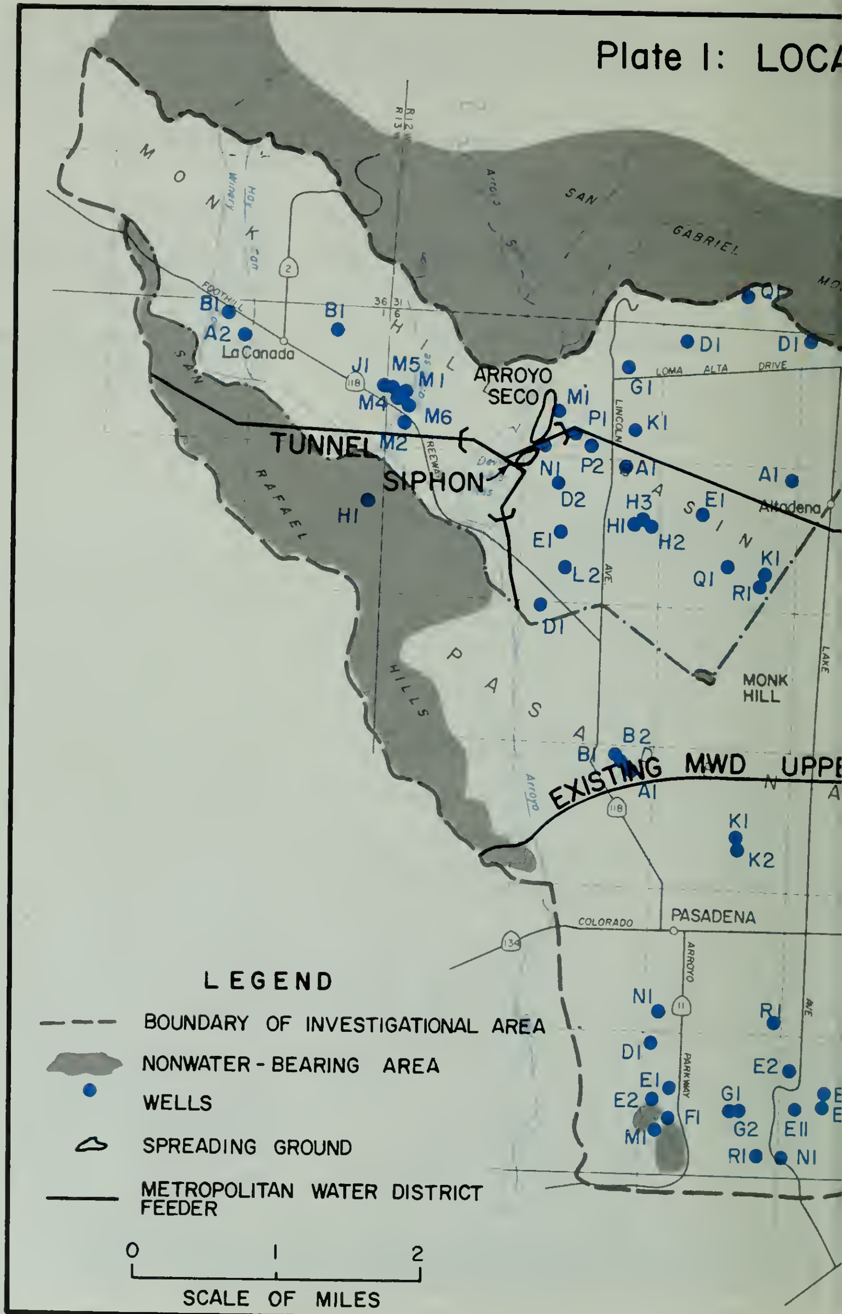


Plate I: LOCA
LEGEND
BOUNDARY OF INVESTIGATIONAL AREA
NONWATER-BEARING AREA
WELLS
SPREADING GROUND
METROPOLITAN WATER DISTRICT FEEDER
0
1
2
SCALE OF MILES
MONK
SAN GABRIEL
SAN RAFAEL HILLS
PASADENA
ARROYO SECO
TUNNEL
SIPHON
EXISTING MWD UPPE
La Canada
Altadena
MONK HILL
COLORADO
LOMA ALTA DRIVE
LINCOLN AVE.
ARROYO PARKWAY
LAKE AVE
FOOTHILL
R12W
R13W
36
31
6
B1
A2
J1
M5
M1
M4
M6
M2
H1
N1
D2
E1
L2
D1
P1
P2
G1
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H3
H1
H2
Q1
R1
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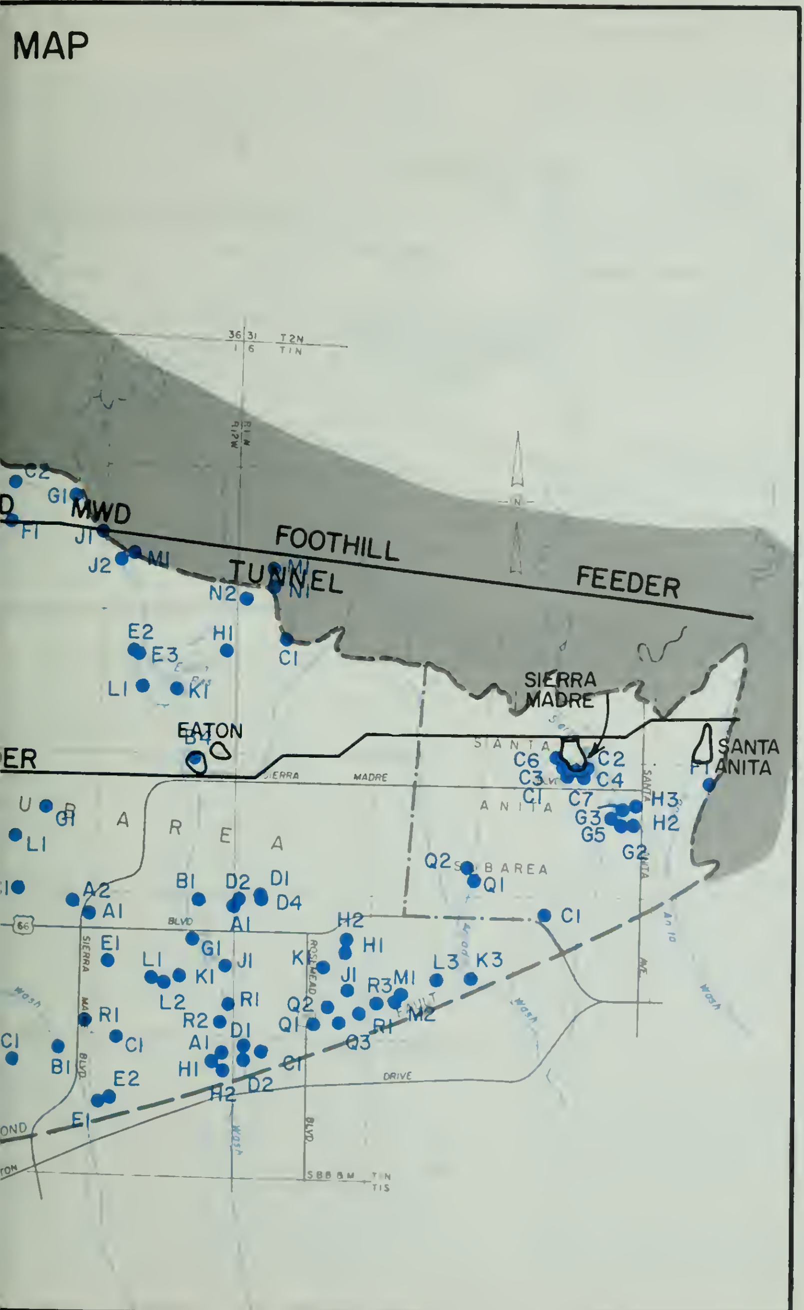
K2
F1
G2
E2
E11
Q2


MAP
FOOTHILL
TUNNEL
FEEDER
MWD
SIERRA MADRE
SANTA ANITA
EATON
ER
SANTA ANITA
SIERRA MADRE
BLVD
DRIVE
T2N
T1N
SB B & M

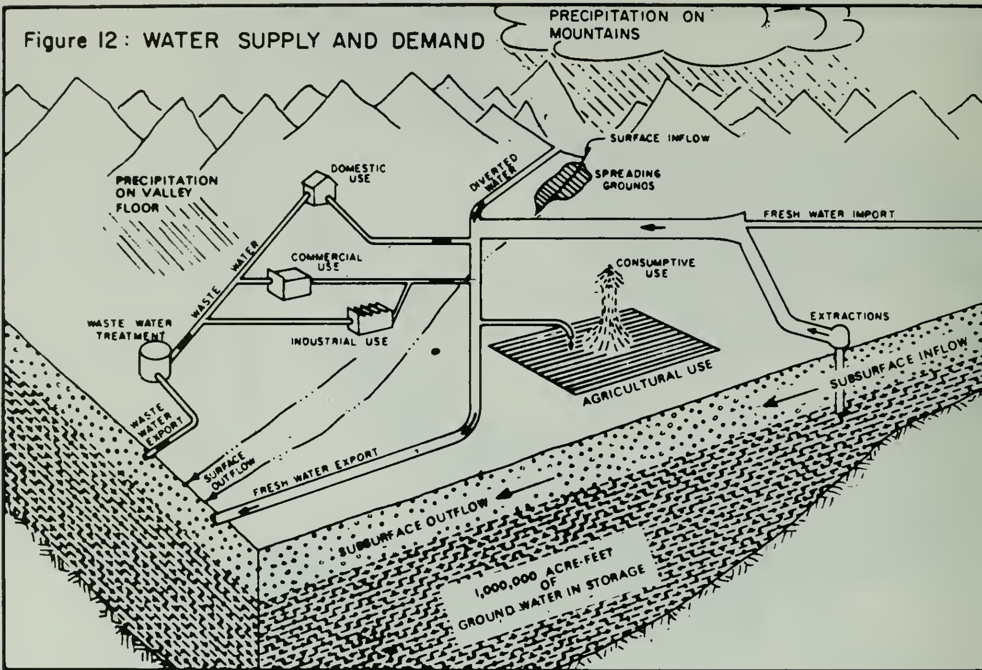



Figure 12: WATER SUPPLY AND DEMAND

In the selection of a plan to operate the ground water basin as a part of the total water resources management in the Raymond Basin Area, the basic question is, how can the water demand of the area be satisfied with the greatest net benefit (i.e., benefit minus cost)? Because the demand for delivered water is considered to be the same under each alternative plan, the answer lies in developing the full range of alternative operational plans, making a cost estimate for each plan, and comparing them. However, one should recognize that political, legal, social, and organizational forces may play a dominant role in the selection and they often override or modify cost and benefit considerations. That is why only the local water organizations, which are intimately acquainted with these forces in their own area, should make the selection of a plan.

In developing the alternative plans, the two extremes are: (1) to rely exclusively upon the ground water basin as a source of water and (2) to use imported water exclusively. Between these two extremes lie a great range of possible alternative plans, as may be surmised from studying Figure 12.

Operational possibilities for using the ground water in storage are also numerous. The amount of ground water in storage could be increased, it could be left unchanged, or it could be decreased from the present level.

## Formulation of Alternative Plans

In formulating the alternative plans, the following were considered to be the basic requirements to be met: (1) The projected water demand for each operational area throughout the study period 1970-2020 will be met; (2) all surface water that can be diverted and distributed through existing facilities will be put to direct beneficial use; (3) all conservable local storm runoff will be spread in existing spreading grounds; (4) ground water for each alternative plan will be used in such a way that neither waterlogging nor dewatering of aquifers will take place; (5) imported water will be delivered either directly to users or recharged (State Water Project water only) in spreading grounds for subsequent pumping and delivery to users; and (6) no rising water will take place.

As has been pointed out, a number of alternative plans, using various combinations of ground and imported waters, are physically possible. Four of them (Plans A-D) were selected for detailed economic analysis by the Department and local agencies.

For two of the plans (A and C), the assumption had been made that ground water extractions will be increased above those of the "Decreed Right 1955", but for the other two (B and D) extractions will be limited to those of the "Decreed Right 1955", which is 30,622 acre-feet per year (including exports to the San Gabriel Basin).

Under Plan A, the ground water extracted will increase by 4,600 acre-feet per year in 1970 and by 7,500 acre-feet per year in 2020. In addition, 15,000 acre-feet per year of water from the State Water Project will be spread beginning in 1980.

In Plan B, which holds to the "Decreed Right 1955" extraction, 7,000 acre-feet per year of water from the State Water Project will be spread beginning in 1980. This plan results in a safe yield operation of the basin.

Under Plan C, the ground water extracted will increase above the "Decreed Right

Table 9: RESIDUAL WATER DEMAND AND LOCAL WATER SUPPLY
1970-2020
In thousands of acre-feet

| Operational area | Local water supply* | Residual Water Demand 1970 | 1975 | 1980 | 1985 | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.1 | 1.8 | 1.8 | 1.9 | 1.9 | 1.9 | 2.0 | 2.0 | 2.0 | 2.0 | 2.1 | 2.1 |
| 2 | 0 | 2.5 | 2.7 | 2.8 | 2.9 | 2.9 | 3.0 | 3.0 | 3.1 | 3.1 | 3.2 | 3.2 |
| 3 | 1.8 | 14.2 | 15.2 | 16.1 | 16.9 | 17.6 | 18.1 | 18.5 | 18.8 | 19.0 | 19.3 | 19.4 |
| 4 | 0.6 | 5.8 | 6.1 | 6.4 | 6.6 | 6.8 | 7.0 | 7.2 | 7.3 | 7.4 | 7.5 | 7.6 |
| 5 | 1.3 | 14.1 | 14.9 | 15.7 | 16.4 | 16.9 | 17.4 | 17.7 | 18.0 | 18.2 | 18.4 | 18.5 |
| 6 | 0 | 2.1 | 2.2 | 2.3 | 2.4 | 2.5 | 2.5 | 2.6 | 2.6 | 2.7 | 2.7 | 2.8 |
| 7 | 0 | 4.7 | 5.2 | 5.6 | 6.0 | 6.5 | 6.9 | 7.4 | 7.8 | 8.1 | 8.4 | 8.6 |
| 8 | 0.5 | 2.2 | 2.3 | 2.5 | 2.7 | 2.9 | 3.0 | 3.1 | 3.2 | 3.3 | 3.3 | 3.4 |
| Total | 4.3 | 47.4 | 50.4 | 53.3 | 55.8 | 58.0 | 59.9 | 61.5 | 62.8 | 63.8 | 64.9 | 65.6 |

* Based on 31-year average stream diversions (1932-33 to 1962-63). Diversions not included if none since 1940.

1955" by 8,400 acre-feet per year in 1980 and by 13,000 acre-feet per year in 2020. An annual amount of 16,000 acre-feet of water from the State Water Project will be spread starting in 1980.

Plan D, under which extractions will be limited to the amount of the "Decreed Right 1955", none of the imported water from the State Water Project will be spread.

## Items Common to All Plans of Operation

In developing the alternative plans, some items were found to be common to all plans; others varied according to the specific plan.

Local Water Supply. In this report, local water supply means (1) ground water that is transferred from one operational area to another and (2) surface water that is diverted for direct use. It was assumed to be the same for all plans.

The transfer of ground water from one operational area to another was based on a 9-year average (1961-69). The surface diversions to each operational area for direct use were based on the 31-year base period average. Diversions were not included if none had occurred since 1940.

The difference between the projected water demand, shown in Table 1, and the local water supply, shown in Table 9, constitutes a residual water demand. This is the demand that must be satisfied by the alternative plans. Table 9 shows the estimated residual water demand for each operational area.

Replenishment and Dimunition of Ground Water. In the formulation of alternative plans, hydrologic items that either replenish or diminish ground water in storage must be considered. Some of these items can be assumed to have equal effects on all plans. They are deep percolation of precipitation, streamflow, and delivered water; the recharge of native water; subsurface inflow and outflow; and ground water exported. Table 2 shows these items that are assumed to be common to all plans of operation.

## Operational Variables

In all plans of operation, four items were assumed to be variable: (1) amount of extractions, (2) location of extractions, (3) amount of artificial recharge of imported water, and (4) location of artificial recharge of imported water.

Amount of Extractions. The amount of extraction was set at an amount equal to the difference between the residual water demand and the imported water. If a large amount of imported water is used, the amount of ground water extracted would be correspondingly small.

Table 10 shows the amount of extractions for the four selected plans.

Location of Extractions. Under each plan of operation, the amounts of extraction were established initially for each operational area. Then these amounts were distributed to nodes within the operational area, based on the ratio of the nodal to the operational area extraction that existed in 1968. These were adjusted for some plans to avoid dewatering of some nodes.

Table 10: ESTIMATED INFLOW TO AND OUTFLOW FROM THE ZONE OF SATURATION[a]

1970-2020
In thousands of acre-feet

| Year | Net inflow common to all plans[b] | Plans A and B: Inflow: Imported water spread | Plans A and B: Inflow: Total | Plans A and B: Outflow: Pumped extractions | Plans A and B: Net change in storage | Plans C and D: Inflow: Imported water spread | Plans C and D: Inflow: Total | Plans C and D: Outflow: Pumped extractions | Plans C and D: Net change in storage |
|---|---|---|---|---|---|---|---|---|---|
| | | Plan A | | | | Plan C | | | |
| 1970 | 19.4 | 0.0 | 19.4 | 29.9 | -10.5[c] | 0.0 | 19.4 | 25.4 | -6.0[e] |
| 1975 | 19.4 | 0.0 | 19.4 | 30.6 | -11.2[c] | 0.0 | 19.4 | 25.4 | -6.0[e] |
| 1980 | 19.4 | 15.0 | 34.4 | 31.3 | + 3.1[c] | 16.0 | 35.4 | 33.8 | +1.6[e] |
| 1985 | 19.4 | 15.0 | 34.4 | 31.8 | + 2.6[c] | 16.0 | 35.4 | 34.8 | +0.6[e] |
| 1990 | 19.4 | 15.0 | 34.4 | 32.1 | + 2.3[c] | 16.0 | 35.4 | 35.6 | -0.2[e] |
| 1995 | 19.4 | 15.0 | 34.4 | 32.2 | + 2.2[c] | 16.0 | 35.4 | 36.1 | -0.7[e] |
| 2000 | 19.4 | 15.0 | 34.4 | 32.3 | + 2.1[c] | 16.0 | 35.4 | 36.7 | -1.3[e] |
| 2005 | 19.4 | 15.0 | 34.4 | 32.5 | + 1.9[c] | 16.0 | 35.4 | 37.3 | -1.9[e] |
| 2010 | 19.4 | 15.0 | 34.4 | 32.6 | + 1.8[c] | 16.0 | 35.4 | 37.7 | -2.3[e] |
| 2015 | 19.4 | 15.0 | 34.4 | 32.7 | + 1.7[c] | 16.0 | 35.4 | 38.1 | -2.7[e] |
| 2020 | 19.4 | 15.0 | 34.4 | 32.8 | + 1.6[c] | 16.0 | 35.4 | 38.4 | -3.0[e] |
| | | Plan B | | | | Plan D | | | |
| 1970 | 19.4 | 0.0 | 19.4 | 25.4 | - 6.0[d] | 0.0 | 19.4 | 25.4 | -6.0[f] |
| 1975 | 19.4 | 0.0 | 19.4 | 25.4 | - 6.0[d] | 0.0 | 19.4 | 25.4 | -6.0[f] |
| 1980 | 19.4 | 7.0 | 26.4 | 25.4 | + 1.0[d] | 0.0 | 19.4 | 25.4 | -6.0[f] |
| 1985 | 19.4 | 7.0 | 26.4 | 25.4 | + 1.0[d] | 0.0 | 19.4 | 25.4 | -6.0[f] |
| 1990 | 19.4 | 7.0 | 26.4 | 25.4 | + 1.0[d] | 0.0 | 19.4 | 25.4 | -6.0[f] |
| 1995 | 19.4 | 7.0 | 26.4 | 25.4 | + 1.0[d] | 0.0 | 19.4 | 25.4 | -6.0[f] |
| 2000 | 19.4 | 7.0 | 26.4 | 25.4 | + 1.0[d] | 0.0 | 19.4 | 25.4 | -6.0[f] |
| 2005 | 19.4 | 7.0 | 26.4 | 25.4 | + 1.0[d] | 0.0 | 19.4 | 25.4 | -6.0[f] |
| 2010 | 19.4 | 7.0 | 26.4 | 25.4 | + 1.0[d] | 0.0 | 19.4 | 25.4 | -6.0[f] |
| 2015 | 19.4 | 7.0 | 26.4 | 25.4 | + 1.0[d] | 0.0 | 19.4 | 25.4 | -6.0[f] |
| 2020 | 19.4 | 7.0 | 26.4 | 25.4 | + 1.0[d] | 0.0 | 19.4 | 25.4 | -6.0[f] |

a. Annual inflow, outflow, and change in storage estimated by straight line interpolation between five-year intervals.
b. From Table 2

Accumulated change in storage for the period 1970 through 2020 is:

c. +10,000 acre-feet
d. 0.
e. -92,000 acre-feet
f. -300,000 acre-feet

Amount of Imported Water Spread. The amount of imported water spread was limited by the capacity of the spreading grounds. The capacity of each is the anticipated annual recharge capacity as given in Table 8.

For the study, the only imported water assumed to be spread was that from the State Water Project via the MWD system. The amounts of this imported water and native water spread are shown in Table 11.

Location of Spreading of Imported Water. Imported water can be spread in all the major existing spreading grounds. No additional acreage for spreading grounds appear to be needed because the present percolation capacity of the spreading grounds is enough to accommodate the combined amount of local runoff and maximum amount of imported water spread in the plans studied.

### Four Selected Plans of Operation

As mentioned previously, four plans of operation were selected for economic analysis. In all the plans, water from the State Water Project will be imported via the MWD system, but in varying amounts. It may be either delivered directly to users or spread for subsequent pumping.

The summary of the selected plans of operation is shown in Table 12. The summary of extractions and direct

Table 11: GROUND WATER RECHARGE UNDER SELECTED PLANS

| Spreading Grounds | Recharge Water, in Acre-feet per Year | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Plan A | | | Plan B | | | Plan C | | | Plan D | | |
| | Native | State* | Total | Native | State* | Total | Native | State* | Total | Native | State* | Total |
| Arroyo Seco | 580 | 3,620 | 4,200 | 580 | 2,000 | 2,580 | 580 | 3,620 | 4,200 | 580 | 0 | 580 |
| Eaton Wash | 500 | 5,140 | 5,640 | 500 | 2,000 | 2,500 | 500 | 5,140 | 5,640 | 500 | 0 | 500 |
| Santa Anita | 430 | 2,040 | 2,470 | 430 | 1,000 | 1,430 | 430 | 2,040 | 2,470 | 430 | 0 | 430 |
| Sierra Madre | 1,540 | 4,200 | 5,740 | 1,540 | 2,000 | 3,540 | 1,540 | 5,200 | 6,740 | 1,540 | 0 | 1,540 |
| Total | 3,050 | 15,000 | 18,050 | 3,050 | 7,000 | 10,050 | 3,050 | 16,000 | 19,050 | 3,050 | 0 | 3,050 |

* State Water Project water spread via the proposed MWD Foothill Feeder

Table 12: SELECTED PLANS OF OPERATION

| Plans | Assumptions | | | | | |
|---|---|---|---|---|---|---|
| | Extraction a/ Limited to "Decreed Right, 1955" b/ | | 1,000's of Acre-feet per Year | | | Change in Storage, in 1,000 Acre-feet (1970-2020) |
| | Yes | No | Increase Extraction a/ | Spread c/ (1980-2020) | Direct Delivery d/ (1970-2020) | |
| Plan A (Increase Extraction & Spread) | | X | 4.6 to 7.5 e/ | 15 | 17.5 to 32.7 | +10 |
| Plan B (Safe Yield) | X | | None | 7 | 22.1 to 40.2 | 0 |
| Plan C (Maximum Extraction & Spread) | | X | 8.4 to 13.0 f/ | 16 | 22.1 to 27.2 | -92 |
| Plan D (Decreed Right) | X | | None | 0 | 22.1 to 40.2 | -300 |

a/ Includes export (5,250 acre-feet per year) to agencies outside Raymond Basin.
b/ Extractions total 30,622 acre-feet per year, including export.
c/ State Water Project Water imported via MWD system. MWD has announced that delivery has been moved to 1986 from 1978, the date used for this study (and reported as 1980 here because input data for the computer are on 5-year increments).
d/ Includes direct delivery of Colorado River water and State Water Project water via the MWD system.
e/ 1970-2020
f/ 1980-2020

delivery and spreading of State Water Project water is shown in Table 13.

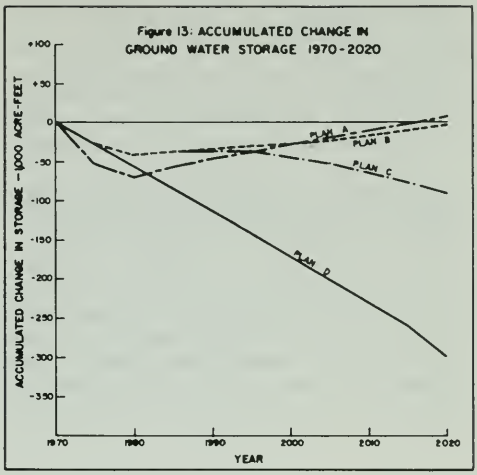


Figure 13: ACCUMULATED CHANGE IN GROUND WATER STORAGE 1970-2020

Change in Storage. By using a mathematical model of the basin, the change in storage was determined for each plan of operation; values of change are shown in Table 12. The accumulated change in storage versus time for each plan of operation, based on mean hydrologic conditions of the base period, is shown in Figure 13.

Plans A and B generally show the same rising curve after 1980 and result in almost no change in storage in 2020. The curve for Plan D declined steadily until 2020. Plan C shows a curve matching that of Plan B until 1990 and then

Table 13: EXTRACTIONS AND IMPORTS FOR RAYMOND BASIN, in 1,000 acre-feet

| Year | Extractions* | | | | State Water Project Water Imported via MWD System | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Direct Delivery (Domestic & Municipal) | | | | Spread | | | |
| | Plan | | | | Plan | | | | Plan | | | |
| | A | B | C | D | A | B | C | D | A | B | C | D |
| 1970 | 35.2 | 30.6 | 30.6 | 30.6 | 17.5 | 22.1 | 22.1 | 22.1 | 0 | 0 | 0 | 0 |
| 1975 | 35.9 | | 30.6 | | 19.9 | 25.1 | 22.1 | 25.1 | 0 | 0 | 0 | |
| 1980 | 36.6 | | 39.0 | | 22.1 | 28.0 | 19.6 | 28.0 | 15.0 | 7.0 | 16.0 | |
| 1985 | 37.1 | | 40.0 | | 24.1 | 30.5 | 21.1 | 30.5 | | | | |
| 1990 | 37.4 | | 40.8 | | 26.0 | 32.7 | 22.4 | 32.7 | | | | |
| 1995 | 37.5 | | 41.3 | | 27.8 | 34.6 | 23.9 | 34.6 | | | | |
| 2000 | 37.6 | | 41.9 | | 29.3 | 36.2 | 24.9 | 36.2 | | | | |
| 2005 | 37.8 | | 42.5 | | 30.4 | 37.5 | 25.6 | 37.5 | | | | |
| 2010 | 37.9 | | 42.9 | | 31.3 | 38.5 | 26.2 | 38.5 | | | | |
| 2015 | 38.0 | | 43.3 | | 32.3 | 39.6 | 26.9 | 39.6 | | | | |
| 2020 | 38.1 | 30.6 | 43.6 | 30.6 | 32.7 | 40.2 | 27.2 | 40.2 | 15.0 | 7.0 | 16.0 | 0 |

* Includes export (5,250 acre-feet per year) to agencies outside the Raymond Basin.

declines steadily. Plan A has the smallest amount of ground water in storage in 1980 because of the increased extractions from 1970. Plan C also has increased extractions from 1980, but this is compensated for by the start of spreading operations in that year.

Change in Ground Water Level Elevations. Changes in the amount of ground water in storage affect the ground water level elevations in the basin. Water level elevations were estimated by use of the mathematical model for each plan of operation starting from 1970. The initial 1970 ground water level elevations are shown in Figure 14. Maps showing contour lines of computed equal changes in ground water levels between 1970 and 1990 and between 1970 and 2020 for the four plans are shown in Figures 15-A through 15-D and Figures 16-A through 16-D. It should be emphasized here that water level changes vary widely in the basin and that study of these figures is necessary to get the true picture of the changes in water levels.

Figures 15-A through 15-D show that from 1970 to 1990 the following changes in ground water level occur: (1) in Plan A, the maximum change in water level of about - 60 feet occurs just south of Monk Hill; (2) in Plan B, the change in water levels throughout the

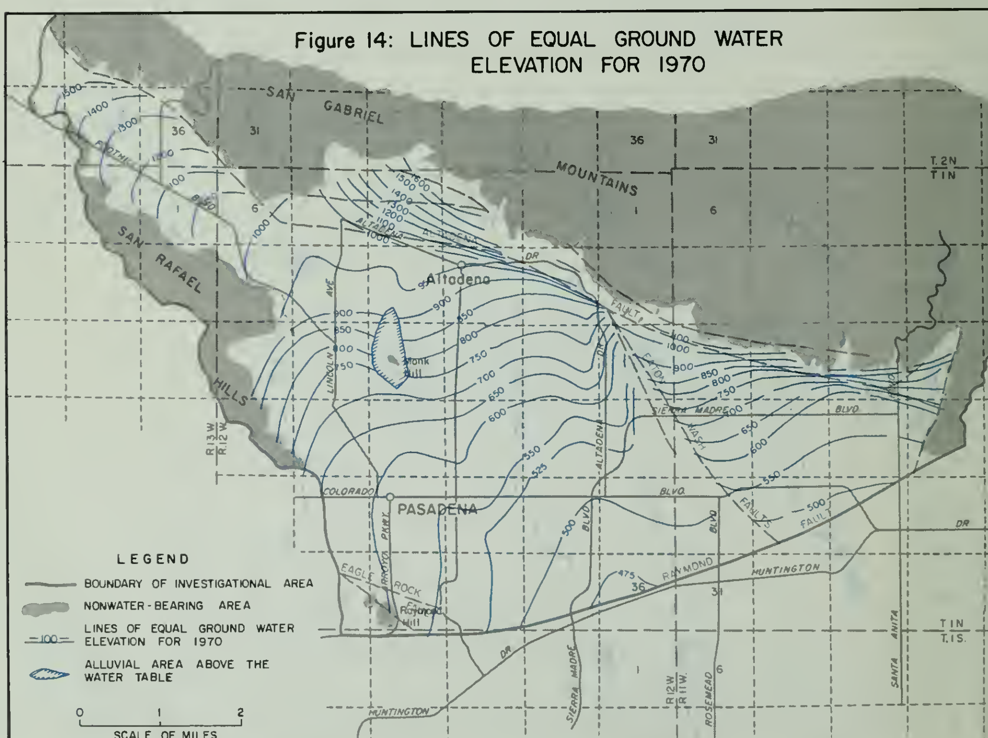



Figure 14: LINES OF EQUAL GROUND WATER ELEVATION FOR 1970

basin is less than for the other plans; (3) in Plan C, the maximum change in water level of about -70 feet is indicated in the vicinity of Monk Hill; and (4) in Plan D, a general decline of water levels is shown with the maximum of -140 feet indicated near the east end of the basin.

Figures 16-A through 16-D show that from 1970 to 2020 the following changes in ground water level occur: (1) in Plan A, water levels increase near the east end of the basin; (2) in Plan B, the change in water levels throughout the basin is again less than for the other plans; (3) in Plan C, maximum change in water level of -250 feet occurs south of Monk Hill*; and (4) in Plan D, water levels generally decline with the maximum of -300 feet occurring at the east end of the basin.

* The pumping trough just south of Monk Hill can be partially eliminated by spreading more imported water at the Eaton Wash spreading grounds. This spreading ground can handle an additional 2,500 acre-feet of spreading above that used for Plan C. However, additional amounts of spreading will have to be checked for possible waterlogging. In addition, some control of pumping can be made to avoid too sharp a drop of water levels in local areas.

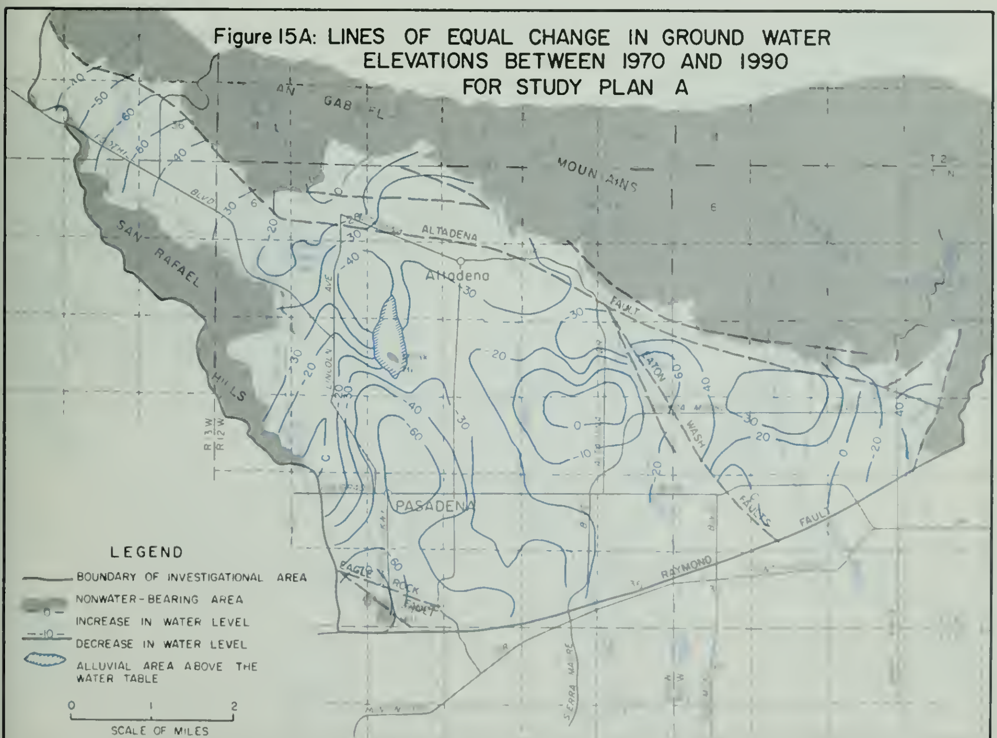



Figure 15A: LINES OF EQUAL CHANGE IN GROUND WATER ELEVATIONS BETWEEN 1970 AND 1990 FOR STUDY PLAN A

## Cost of Each Plan

Those items that were considered in computing the cost of each plan are those whose associated costs would be different under different alternatives: pumping ground water, importing water for direct delivery and for spreading, boosting and pumping to operating head, constructing laterals and outlet structures for spreading, and deepening wells. Costs for possible water quality degradation and land subsidence from ground water level decline were expected to be minor and, therefore, were excluded.

### Cost of Pumping Ground Water

The annual cost of pumping ground water was computed for each node. First, the nodal lift was computed. This was done as follows:

$$H = S - W + 40$$

Where H = static lift plus drawdown of each node in feet

S = surface level elevation

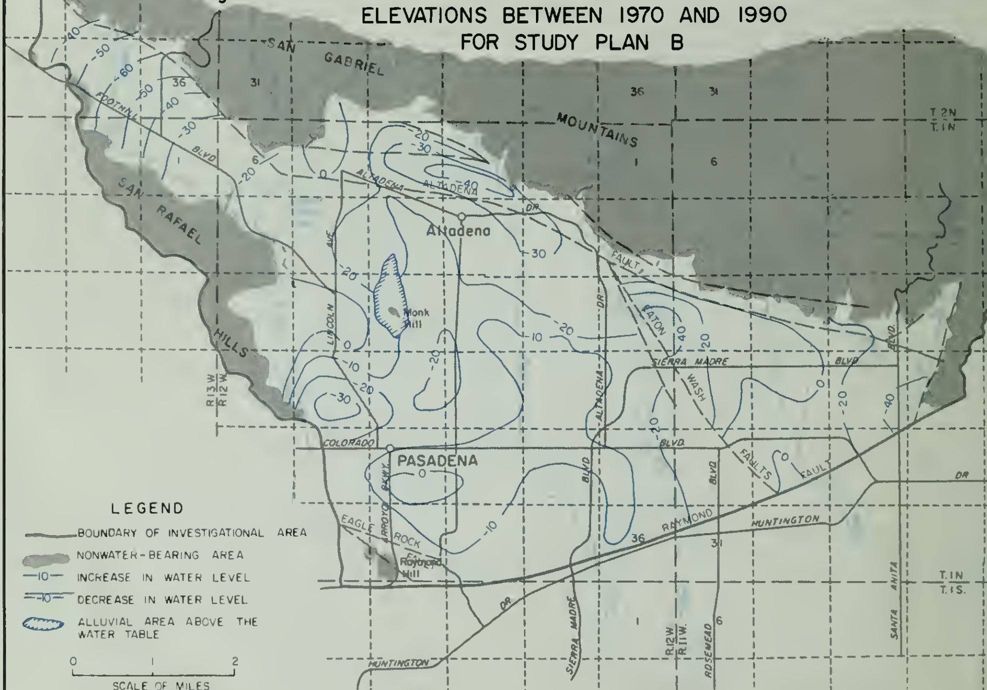
W = water level elevation

40 = average drawdown, in feet

Using this value of the lift for each node, the annual cost of pumping was computed as follows:

$$C = 0.033\ (Ext)\ (H)$$

Figure 15B: LINES OF EQUAL CHANGE IN GROUND WATER ELEVATIONS BETWEEN 1970 AND 1990 FOR STUDY PLAN B



Where C = cost of pumping each year per node

0.033 = cost in dollars per acre-foot per foot of lift.

Ext = extraction in acre-feet per node including export

H = nodal lift, in feet

The cost of boosting and pumping to operating head is discussed later.

## Cost of Imported Water

Cost of imported water for direct delivery was computed by using the varying annual rates for domestic water. These rates range from \$53 per acre-foot to \$117 per acre-foot including surcharge for treatment (softened and filtered), as shown in Table 14.

**Table 14: PROJECTED PRICING FOR IMPORTED WATER VIA MWD***
In dollars per acre-foot

| Year | Direct Delivery (Domestic and municipal) | | | Spread | | |
|---|---|---|---|---|---|---|
| | Untreated | Surcharge for Treatment | Total | Untreated | Operation & Maintenance | Total |
| 1970 | 44 | 9 | 53 | 22 | 5 | 27 |
| 1975 | 68 | 14 | 82 | 39 | 5 | 44 |
| 1980 | 85 | 15 | 100 | 60 | 5 | 65 |
| 1985 | 87 | 16 | 103 | 62 | 5 | 67 |
| 1990 | 90 | 16 | 106 | 65 | 5 | 70 |
| 1995 | 92 | 16 | 108 | 66 | 5 | 71 |
| 2000 | 95 | 16 | 111 | 69 | 5 | 74 |
| 2005 | 97 | 16 | 113 | 71 | 5 | 76 |
| 2010 | 100 | 17 | 117 | 73 | 5 | 78 |
| 2015 | 98 | 16 | 114 | 71 | 5 | 76 |
| 2020 | 95 | 15 | 110 | 70 | 5 | 75 |

* Estimate only for this study and not to be considered official MWD policy. (Based on information from MWD and Raymond Basin Advisory Committee)

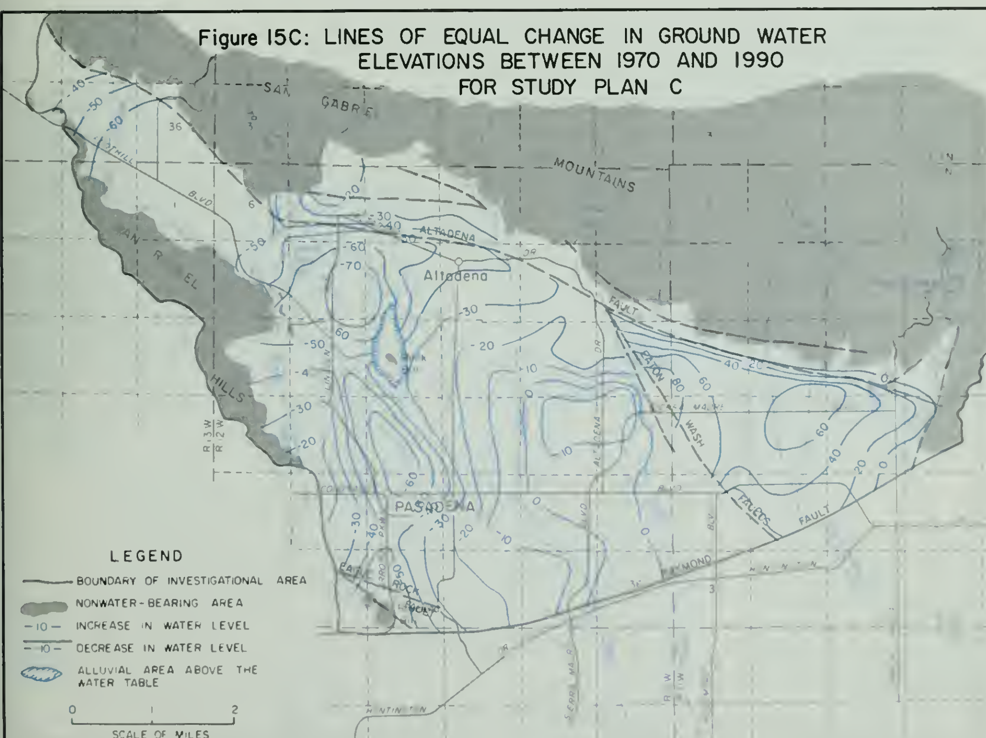


Figure 15C: LINES OF EQUAL CHANGE IN GROUND WATER ELEVATIONS BETWEEN 1970 AND 1990 FOR STUDY PLAN C

Cost of imported State Water Project water for spreading was computed by using the replenishment rates shown in Table 14. The annual operation and maintenance (O & M) cost of spreading was estimated to be $5 per acre-foot.

## Cost of Boosting and Pumping to Operating Head

Costs of boosting and pumping to operating head were assumed to apply to only those extractions exceeding the "Decreed Right 1955" extractions (Plans A and C). Decreed right extractions were considered to be a common item only in calculating cost of boosting and pumping to operating head.

Of the increased extractions, 40 percent were considered to be pumped to reservoirs, 30 percent to operating head (100-foot lift), and 30 percent to boosters (100-foot lift).

The cost was then computed as follows:

$$\text{Cost} = .30 \text{ Ext } \left[(100 \times 0.033) + 5.85\right]$$

Where .30 = 30 percent of increased extraction

Ext = extraction in excess of "Decreed Right 1955" extraction

.033 = cost in dollars per acre-foot per foot of lift.

100 = average discharge head

5.85 = cost in dollars of boosting an acre-foot of water 100 feet.

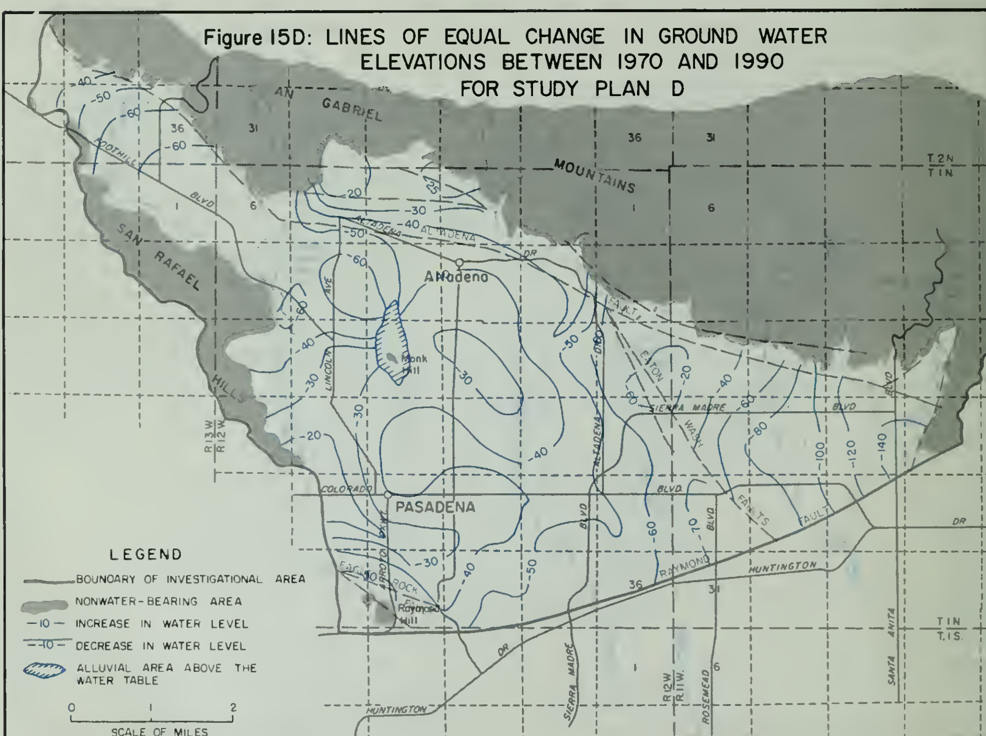


Figure 15D: LINES OF EQUAL CHANGE IN GROUND WATER ELEVATIONS BETWEEN 1970 AND 1990 FOR STUDY PLAN D

## Cost of Laterals and Outlet Structures for Spreading

The existing facilities for all the spreading grounds were considered to be of adequate capacity to handle spreading of imported water. The only additional costs would be for laterals from the proposed MWD Foothill Feeder and for outlet structures.

## Cost of Deepening Wells

The only one of the four selected plans requiring wells to be deepened is Plan D, which results in the greatest lowering of ground water levels.

The assumption was that 50 wells would be drilled to an additional depth of 200 feet for this plan in 1995.

## Water Quality

The cost for possible ground water quality degradation was excluded because a comparison of the quality of ground water in the past and of the imported water to be available in the future indicated that the quality in the ground water basin will not vary substantially under the different plans of operation. In cases that could lead to threatening situations (for example, from potential waste discharges) sufficient steps were assumed to be taken by the California Regional Water Quality Control Board, Los Angeles Region, and other public agencies, in time to prevent any significant damage to the water resources. Therefore, the economic effect associated with the change in water quality under different plans

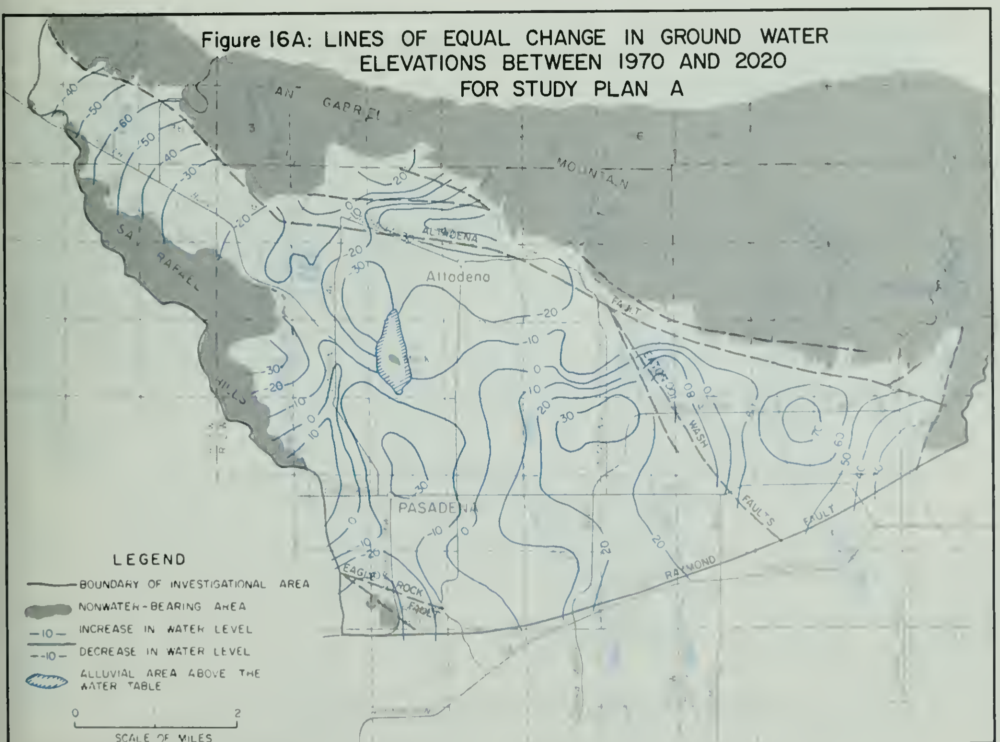



Figure 16A: LINES OF EQUAL CHANGE IN GROUND WATER ELEVATIONS BETWEEN 1970 AND 2020 FOR STUDY PLAN A of operation would be insignificant.

## Land Subsidence

The United States Geological Survey (USGS) has conducted a land subsidence study in the Raymond Basin Area on a cooperative basis with the Department of Water Resources. The USGS was asked for an appraisal of potential subsidence under the assumed future pumping-stress. The Department and USGS agreed that this appraisal would be based on a review of existing leveling data. The USGS reports that the maximum prediction in this area is less than one foot and would be regional rather than concentrated in one location.

Experience in California to date has shown that major damage results from subsidence in two specific types of areas: (1) those immediately adjacent to the ocean where levees and local facilities may become inundated and (2) those where long, low gradient, open channels cross the subsidence area. Because neither of these types of areas matches the areas of possible subsidence, damage from this cause is considered to be negligible.

## Economic Evaluation

### Present Worth

The cost of water service for the study area for each plan from 1970 through 2020 consists of the total of all costs enumerated above. Because certain of the costs will be incurred at different times under different plans, the economic effect of incurring the same

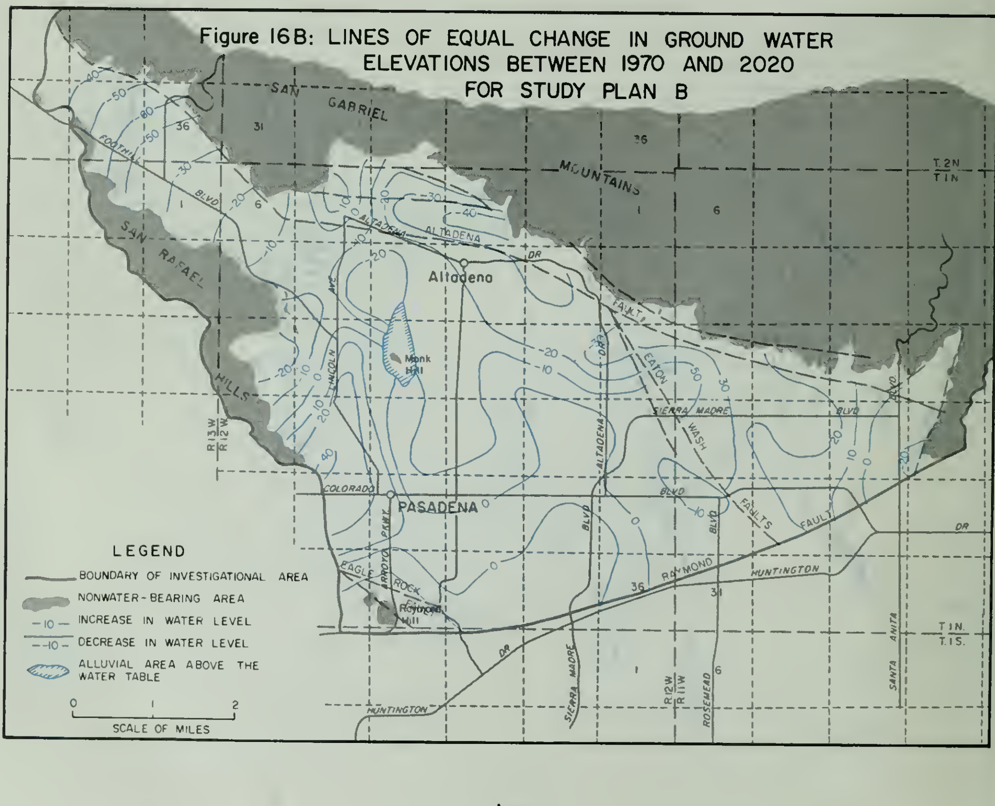


Figure 16B: LINES OF EQUAL CHANGE IN GROUND WATER ELEVATIONS BETWEEN 1970 AND 2020 FOR STUDY PLAN B total cost will vary with the plan. To establish a usable economic comparison of the plans, all costs were converted to the common denominator of present worth.

Present worth of the total cost of water service under each plan may be considered the amount of money that is needed today to meet the future financial obligations associated with the service. Thus, a comparison of the present worth of the four selected plans would provide a comparative measure of the extent of financial obligations that would be imposed on the decision-makers and on the water users they serve. Table 15 shows the total present worth of the variable costs of the four selected plans.

Table 15: PRESENT WORTH COMPAREO WITH CHANGE IN STORAGE 1970-2065

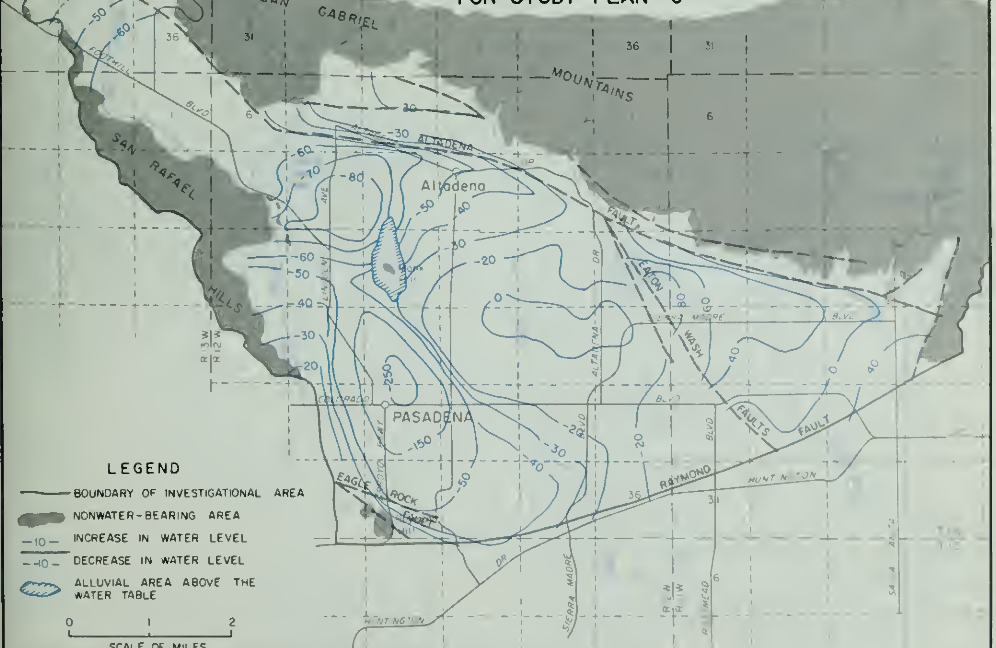
| Item | | Plan A | Plan B | Plan C | Plan D |
|---|---|---|---|---|---|
| Present Worth of Variable Cost, in $1,000* | | | | | |
| 1970-2020 | | | | | |
| Pumping Ground Water | | 5,351 | 4,272 | 5,310 | 5,065 |
| Imported Water | | | | | |
| Direct Delivery | | 44,094 | 55,242 | 41,655 | 55,242 |
| Spread | | 12,699 | 5,927 | 13,545 | 0 |
| Boosters & Pumping to Operating Head** | | 319 | 0 | 350 | 0 |
| Laterals & Outlet Structures for Spreading | | 270 | 270 | 270 | 0 |
| Deepening Wells | | 0 | 0 | 0 | 150 |
| | Total | 62,733 | 65,711 | 61,130 | 60,457 |
| 2020-2055*** | Total | 5,958 | 5,960 | 6,360 | 7,526 |
| 1970-2055 | Total | 68,691 | 71,671 | 67,490 | 67,983 |
| Charge in Storage, in 1,000 Acre-feet | | | | | |
| 1970-2020 | | +10 | 0 | -92 | -300 |
| 2020-2055 | | -310 | -300 | -208 | 0 |
| 1970-2055 | | -300 | -300 | -300 | -300 |

* Based on 5% interest rate.
** Costs applied only to those extractions exceeding "Decreed Right 1955" extractions.
*** Based on assumption that Plan D will be operated on safe yield after 2020 and that Plans A, B, and C will be operated with the use of ground water in storage until level of plan D is reached: 310,000; 300,000; and 208,000 acre-feet, respectively.

## 1970 to 2020

According to the information in Table 15, the four plans show variation in

Figure 16C: LINES OF EQUAL CHANGE IN GROUND WATER ELEVATIONS BETWEEN 1970 AND 2020 FOR STUDY PLAN C



cost from $60 million to $66 million (1970 to 2020).

The differences in costs of pumping ground water, including boosting and pumping to operating head; in costs of laterals and outlet structures for spreading; and in costs of deepening wells are not significant. The major item influencing the present worth costs of the plans is the cost of imported water used for direct delivery or spreading.

## Value of Ground Water

When the total present worth of all plans for 1970 to 2020, as shown in Table 15 are compared, Plan D is found to be the most economical. However, in 2020 each of the other three plans will have more ground water in storage than will Plan D. This additional water in storage has some value if it is put to use. Note that the value of ground water as used here is not the value of water rights.

The economic value of this additional ground water in storage was determined by extending the period of analysis to 2055. This analysis was based on the assumption that, after 2020, Plan D will consist of a safe yield basin operation and Plans A, B, and C will use their ground water in storage (about 310,000 acre-feet, 300,000 acre-feet, and 208,000 acre-feet, respectively) until the ground water levels reach those of Plan D in 2055, as shown in Figure 17.

A second assumption made for this analysis was that, for all plans, the price

Figure 16D: LINES OF EQUAL CHANGE IN GROUND WATER ELEVATIONS BETWEEN 1970 AND 2020 FOR STUDY PLAN D

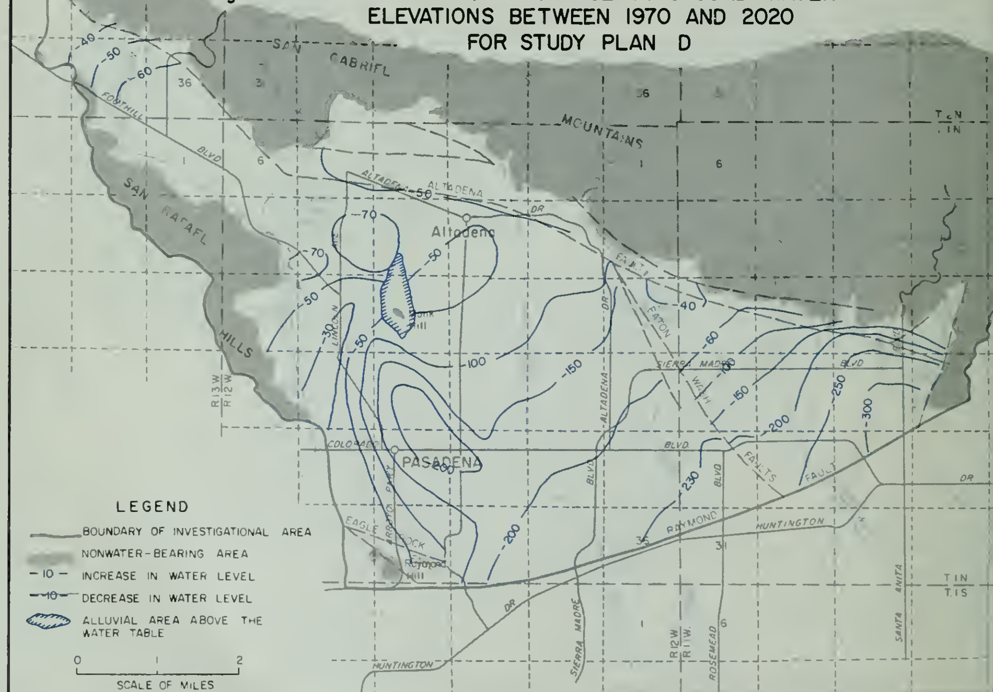
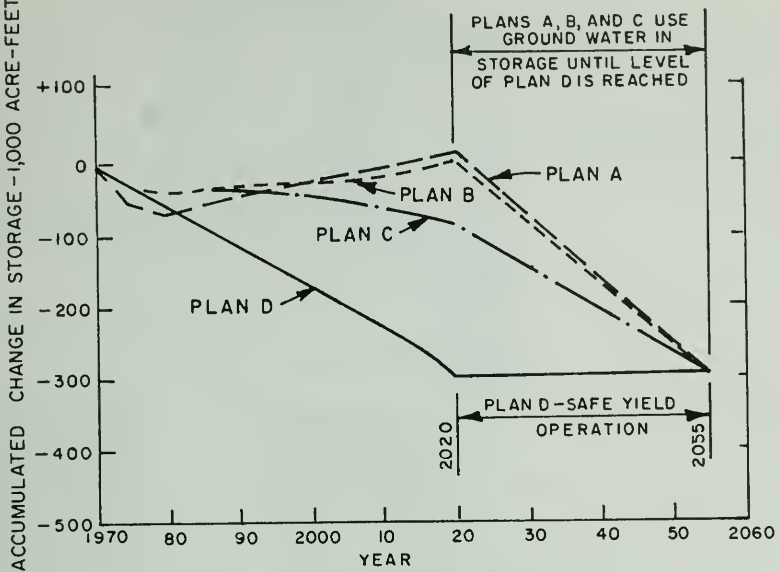


Figure 17: ACCUMULATED CHANGE IN GROUND WATER STORAGE 1970-2055




of water for direct delivery and spreading from 2020 to 2055 will be at the 2020 price, as shown in Table 14.

Thus, the selection of Plans A, B, or C, would delay future importation projects and would result in smaller pumping lifts than Plan D from 2020 to 2055. They would thereby derive substantial savings in the cost of operation of these plans as compared to costs of operating Plan D from 2020 to 2055.

Therefore, the present worth cost from 2020 to 2055 and the total present worth cost from 1970 to 2055 are those shown in Table 15.

Note that the present worth costs of Plans A, C, and D, for 1970 to 2055, differ by only about 2 percent. Plan B exceeds the least cost plan by almost 6 percent. Therefore, on the basis of economics alone, any one of the plans, except Plan B, could justifiably be selected in view of the assumptions and approximations made in this study. Thus, political, legal, and organizational factors would probably dictate the final selection of the plan of water resources management by the local implementing agencies.

Under the present condition, where a mechanism for equitable distribution of gains and losses is not provided, the most economical plan from the standpoint of the entire area may impose unbearable financial burdens on agencies with small financial bases because of substantial lowering of ground water levels and other factors. In the final decision-making, local agencies should consider this type of problem.

Pasadena Public Library

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## Bulletin No. 170 Series, "Abstracts of DWR Publications"

Twice annually, the Department of Water Resources publishes its Bulletin No. 170, "Abstracts of DWR Publications". These reports are free. These reports contain abstracts of all Department of Water Resources technical bulletins published during the previous six months, a cumulative index to those abstracts, a price list of those bulletins published during the past five years which remain in print, and a list of libraries which shelve the bulletins. If you would like your name placed on the mailing list, write to Department of Water Resources, Attn: Reports Administration, P. O. Box 388, Sacramento, CA 95802.

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**Applied Water.** The water delivered to a farmer's headgate in the case of irrigation use or to an individual's meter in the case of urban use or its equivalent. It does not include direct precipitation.

**Artificial Recharge.** For this study, the water which is added to the ground water basin through facilities primarily designed for that purpose, such as spreading basins and injection wells.

**Consumptive Use of Water.** Water consumed by vegetative growth in transpiration and building plant tissue and water evaporated from adjacent soil, from water surfaces, and from foliage. It also includes water similarly consumed and evaporated by urban and nonvegetative types of land use.

**Decreed Right Safe Yield.** Safe yield as determined by the Report of Referee (City of Pasadena v. City of Alhambra, et al Los Angeles County Superior Court No. Pasadena C-1323 33 Cal 2d 908, 207 P. 2d 17 [1949])

**Delivered Water.** The sum of the applied water and any conveyance losses that occur within a study area in the process of delivering this water. For this investigation, delivered water is the sum of the imported water and extractions less the amount of exported water.

**Dewatered Node.** For this study, a node is considered to be dewatered when the water level in the node is equal to or less than 50 feet above the bottom elevation (base of fresh water) of the node.

**Drawdown.** The change in water surface elevation in a well during the extraction of ground water.

**Ground Water.** Subsurface water occurring in the zone of saturation and moving under control of the water table slope or piezometric gradient.

**Ground Water in Storage.** That stage of the hydrologic cycle during which water occurs as ground water in the zone of saturation, including that part of such a stage when water is passing through the zone of aeration and entering or leaving storage.

**Hydraulic Gradient.** Under unconfined ground water conditions, it is the slope of the profile of the water table. Under confined ground water conditions, it is the line joining the elevations to which the water would rise in wells if they were perforated in the aquifer.

**Infiltration.** The flow, or movement, of water through the soil surface into the ground.

**Operational Area.** A subdivision of the study area along service area boundaries for purposes of identifying alternative plans of operation with respect to operational variables.

Percolation. The movement, or flow, of water through the interstices, or pores, of a soil or other porous media.

Percolation, Deep. The movement of water in the zone of aeration from the belt of soil water into and through the intermediate belt.

Period. A specified division, or portion, of time.

Mean. A period chosen as representative of conditions of supply and climate over a long series of years. Because the precipitation during the 31-year base period, 1932-33 through 1962-63, nearly equaled the precipitation that occurred over a longer period of time, this 31-year base period was assumed to represent a long-time mean period for this investigation.

Seasonal. Any 12-month period other than the calendar year. In this study, seasonal period is synonymous to the runoff period, October 1 through September 30.

Pervious Area. A ground surface area that is not paved or otherwise covered by permanent man-made structures.

Rising Water. Ground water from the zone of saturation that rises to the ground surface, usually to a streambed, when the ground surface is at a lower elevation than the ground water table or the piezometric surface of a confined aquifer.

Safe Yield Plan. For this study, under mean hydrologic conditions, a safe yield plan of operation shows no change in storage. Also see Decreed Right safe yield.

Subsurface Water Zones.

Zone of Aeration. The zone above the water table in which the interstices are partly filled with air. This zone lies between the surface and the zone of saturation. Starting from the surface, it includes the belt of soil water, the intermediate belt, and the capillary fringe.

Zone of Saturation. The zone below the water table in which all the interstices are filled with ground water that is moving under the control of the water table slope or piezometric gradient. This zone lies between the zone of aeration and bedrock.

Waste Water. For this study, water that has been put to some use or uses and has been disposed of to a sewer. It may include liquid industrial wastes, sewage, or both, but specifically excludes oil brines.

Water Table. The surface of ground water at atmospheric pressure in an unconfined aquifer. This is revealed by the levels at which water stands in wells penetrating the unconfined aquifer.

# INDEX

This index enters subjects from text and foreword by page number; subjects from tables by table number (T1, T2, etc); subjects from figures by figure number (F1, F2, etc), and subjects from Plate 1 by plate number (P1). The index does not cover either the photographs or the bibliography.